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Radiation and the Population

THE second report of the special independent Committee to the Medical Research Council on the Hazards to Man of Nuclear and Allied Radiations, merits wide publicity not only because of the importance of its contents, but also because of the manner in which it underlines the soundness of the first report published in 1956 and the recommendations that were then made. In the past five years a great deal of research has been undertaken, a great many committees have sat and discussed the general problems both at national and international levels, and new theories relating to hazards and protection have evolved. Scientifically, some of the research results have led to quite fundamental changes in conception, but from the practical point of view the general conclusion is drawn that the dangers had been perhaps a little over-estimated.

It is, of course, traditional that any body of experts, particularly if they are scientific, should be suspect by the population. One of the traditional rights of free men is to counter the professional verdict with the comment that "they don't know everything." This the Committee in its report freely admits and is at pains to draw attention to those areas of uncertainty where the margin for error or the lack of experimental evidence leaves a question of doubt. But not knowing everything is very different from not knowing anything, and few who read this report will afterwards with any conviction be able to assert that Man's present use of radiation is leading to, or is even likely to lead to any population dangers at all. We are, of course, in this context ignoring the possibility of a nuclear war or other national calamity, these are entirely different matters; what is quite clear is that if the standards laid down are adhered to, the dangers from radiation are so negligible as to be completely ignored by the ordinary man who will always have quite enough real perils to contend with.

There were implications following the 1956 report that because it was Western policy to continue atomic bomb testing, the research results had been juggled, or the report rigged, or at any rate the whole discussion angled to minimize the risks that were being run. Many inflammatory statements have been made by people who should know better, based either on complete ignorance or on the assumption that the crucial aspects were being withheld. Such a stand now is completely inadmissible. While, for example, the political implications of continuing atomic bomb tests may be of the most profound importance, the radiation implications (at least so far as any rate of testing attempted to date is concerned) are negligible.

The wide variation in natural background is also a matter that could well be given wide publicity. If radiation were something completely new, to which man had not been subject from the beginning of time, the uncertainties of its effects, particularly long term, would be much greater. When, however, it is generally appreciated that the contribution to the population dose from the peaceful exploitation of nuclear energy, from fall-out, luminous dials, etc., etc., is so small in comparison with the difference (let alone the average values) between the background levels in, say, Aberdeen and Edinburgh, the present dangers of radiation can assume their right perspective.

There is one aspect of the assessment of maximum permissible population levels now generally adopted, not only in this country but all over the world, which we find difficult to follow. Broadly three types of person are considered; those who are occupationally exposed, that is they work in atomic energy establishments, handle radioactive sources, and must expect to receive doses which are significantly greater than background; then there are those in the immediate surrounding area who will be subjected to additional doses resulting from say effluent from the establishment (largely gaseous and some particulate) and those who come into contact with small amounts of radiation as a result of their work, for example, clerical workers in atomic energy establishments; finally, there is the population as a whole. There are subdivisions within these groups and in the setting of maximum permissible doses particular recognition is given to those subsections which will contain children.

If we ignore these subsections and consider the three groups above, the first group is allowed the highest dose on the basis that the maximum permitted is below the level at which damage can occur; the actual dose received by an individual is measured and he is kept under constant medical surveillance in order to check that the clinical evidence is in accord with the radiation evidence. The second group has lower levels defined for it, achieved in practice by ensuring that the environmental level of radiation is such that even in the worst circumstances the individuals will not exceed (and normally will not even approach) the levels that have been laid down. The distinction between these two groups seems reasonable and logical; only adults are included in the first category and each person is individually checked. This is impossible for people in the second group and so an extra factor of safety is added and more stringent assumptions made as regards, for example, the total time they are likely to be exposed. But it is then laid down that the population as a whole should have a still lower dose on average and, furthermore, it is contended that if the integrated dose received by a special section of the population should increase, then, steps should be taken to lower the dose received by the population as a whole in order to maintain the average population dose at the same level.

We are not yet in a position where the special group doses can more than marginally influence the average population dose but such a situation could arise and it is the basic principle of differentiating between the population as a whole and the most critical section of the environmental (as distinct from the occupationally exposed) class that we find illogical. The distinction seems particularly arbitrary

in the case of somatic effects but we suspect that it is equally arbitrary from the genetic standpoint. At present there is little evidence that the genetic effect is cumulative, growing from generation to generation, nor that it is enhanced by the mating of two people both of whom have received the higher dose levels. Even if this were shown to be true, populations are remarkably static and the environment class can be considered as being composed of nearly closed communities. Even more important is the fact that we are considering levels of radiation which are already so low that should such effects be significant, they would have become apparent when comparing the records of districts with widely different background levels.

It would appear that there is a tendency to regard the population as a statistical aggregate rather than as a collection of individuals. This is apparent also in the ICRP's recommendations for the maximum permissible levels of accumulated strontium-90 which are set at 200 SUs in the individual and 67 average over the population. We appreciate that there is likely to be a considerable spread in the characteristics of individuals and that from any average figure there are bound to be big divergencies in the burdens of people subject to a common intake, but is there any virtue in establishing an average which is one third of that believed to be the maximum permissible in the individual? Surely, only the individual is important whilst the average is quite immaterial (except perhaps as an indication of trends).

It is not as if the levels laid down do not already contain a number of factors of safety and are based on maximum sensitivity rather than on a mean figure. This may not seem very important at the present time but when we are dealing with levels which are so close to the background level this can, in certain circumstances, cost a great deal of money. Those who lay down these levels have a duty to the population not only to protect their health in this particular field but also to ensure that they are not loading a technology which can bring so much good, with extravagant limitations.

Reversing the argument, if one accepts that the population figure is a real maximum figure which one would not like to see exceeded, then should not this be applied to the environmental people. If you do not bring the population level up to that of the environment you should be bringing the environment level down to that of the population. A disturbing aspect of this is that at some time in the future emotional forces may demand that this be done and it would then be difficult to argue that the population level had been set unreasonably low.

Apart from the principle, it certainly is bad public relations, so far as atomic energy establishments are concerned and this, of course, applies to power stations as well. The existence of the two levels implies that there is a greater danger to people living in the environment of an establishment than to the population at large. Now, in terms of risks, i.e., risks that have any significance at all so far as the individual, his family and progeny are concerned this is just not true. While we applaud the concern that the MRC, and the other national and international organizations have for our welfare, we do suggest that too much emphasis can be placed on distinguishing between the nearly impossible and the highly impossible and some note be taken of the misinterpretation that can be placed upon such distinctions.

Do We Want Exports?

IT seems peculiarly Gilbertian that while the British Government with one voice is exhorting industry to increase its export effort, it should with the other be doing its best to prevent any such export occurring. We refer to the continued refusal of the Government (in concert with the U.S.) to waive its demands for inspection of an overseas reactor exported from the country, either directly by U.K. representatives or through the IAEA.

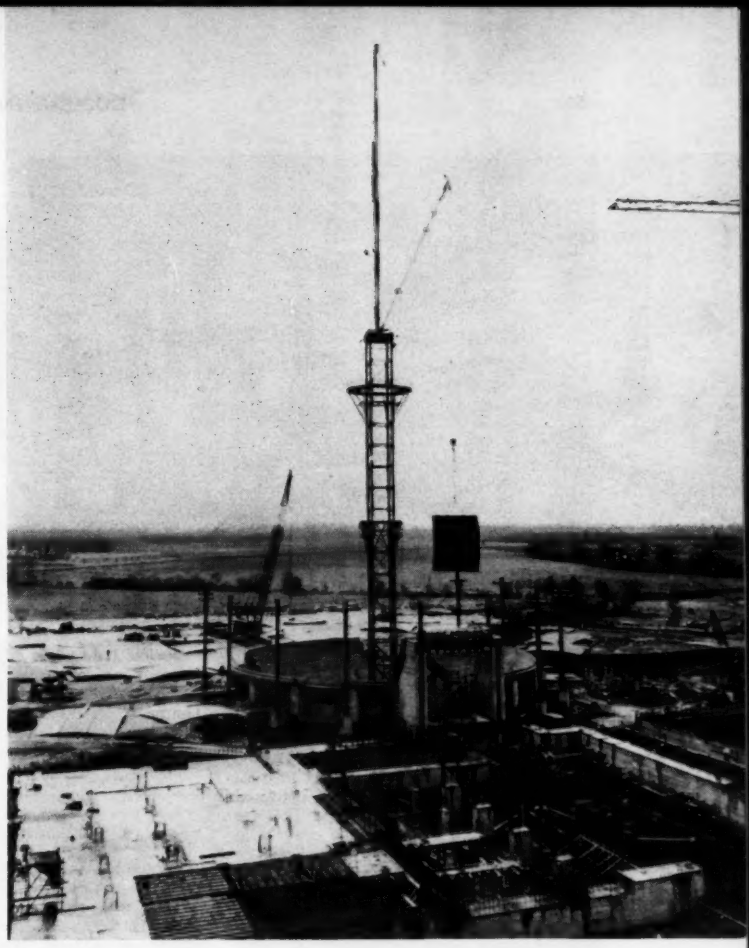
The particular case in point at the present time is India which has firmly requested bids for the 300-MW station at Tarapur but is known to be bitterly opposed to any form of inspection which she regards as a violation of her soyereign rights. We reported the discussions (acrimonious at times) that took place at the IAEA Conference in September (*Nuclear Engineering*, Nov., 1960, p. 487) and hoped that there might be some easing of the situation but this would not appear to have happened.

The recent rumpus over the Israeli project for a 24 MW(th) heavy water reactor for testing purposes has again focused attention on the effeteness and ineffectualness of the Anglo-American policy. It should be quite clear by this time that any country determined to equip itself with nuclear weapons and prepared to pay the bill will do so and no one can stop her; this is not to suggest that either Israel or India have intentions of doing any such thing. While the Government continues to pursue its present line it will make no difference to the number of reactors built but will, of course, prevent our own industry from building them. The moment one country is prepared to furnish nuclear equipment without requiring inspection (and both Russia and France are ready to do this) there ceases to be any point in the United Kingdom or the United States refusing also. We wonder, too, if anyone has seriously considered how such an inspection could be enforced if after the power station were built the country refused to allow it.

It is not as if a company in this country could furnish the reactor design and major components and leave the fuel to the purchasing country, as agreements with the AEA governing the design rights of the Magnox reactors prevent any industrial concern from negotiating with a foreign power without the express permission of the Authority. The AEA's own financial interests are identical to those of industry, its major income, other than Treasury grants, being from the sale of fuel, but it will be compelled to follow the policy formulated by the Foreign Office.

We feel that India perhaps is unduly sensitive to the inspection requirements (unless, of course, she really has ulterior motives) but the basic trouble is in demanding them. It may be that negotiations are already in train that would allow a compromise but there have been no indications that these are taking place and unless they were completed rapidly they would come too late. No industrial organization can afford to put all the drive, effort and investment into the preparation of a tender which it feels will inevitably be sabotaged however good the proposals. The three groups in the U.K. will, of course, be tendering but we do not see, unless the Government is prepared in the very near future to guarantee its full support, how they can possibly put in that extra effort which makes the difference between success and failure, when the competition (notably from France) is so keen.

World Digest



Erection of the 160-ft diameter spherical steel containment vessel for the 150 MW(e) BWR plant under construction at Garigliano, Italy. The plant is scheduled for operation in 1963. General Electric, of California, are supplying the reactor, which is designed to enable its output to be increased by 50%.

International

CERN'S 1961 budget accounts for Fr.Sw 67.7 million. This sum will cover capital expenditure on additional apparatus to be used in conjunction with the accelerators at Meyrin as well as the cost of the very large amounts of electricity consumed by the accelerators.

Reorganization has led to the creation of 12 divisions at CERN to replace the previous six. The new divisions cover: the proton synchrotron, the synchrocyclotron, nuclear physics, engineering, data handling, theory, track chambers, nuclear physics apparatus, accelerator research, site and buildings, finance and general administration.

The FORATOM Steering Committee meets in Rome during March under the chairmanship of Professor Matteini, president.

An agreement for co-operation between the IAEA and the IANEC (Inter-America Nuclear Energy Commission) became effective on December 22 when it was formally signed in Washington by Mr. Sterling Cole, IAEA director general, and Mr. Jesse Perkinson, IANEC executive secretary.

The convention on third-party liability in the field of nuclear energy drawn up between the member states of the ENEA has been published. It appears in both English and French. *Nuclear Engineering* published a review of the convention in the September, 1960, issue (p. 404).

A translation pool has been set up by Euratom, the U.K. AEA and U.S. AEC for the collection and dissemination of information concerning translations of nuclear literature, particularly from such languages unfamiliar to Western readers as Russian and Japanese. Headquarters are at Brussels, from which a monthly "Transatom Bulletin" will be published, listing new and planned translations available in member participating countries.

Euratom is to establish at Karlsruhe an institute for research into transuranium elements. It will cost about DM60 million (about £5.1 million) of which one-third will be contributed by the Bundes Ministry of Atomic Energy.

The Consortia and Oldbury

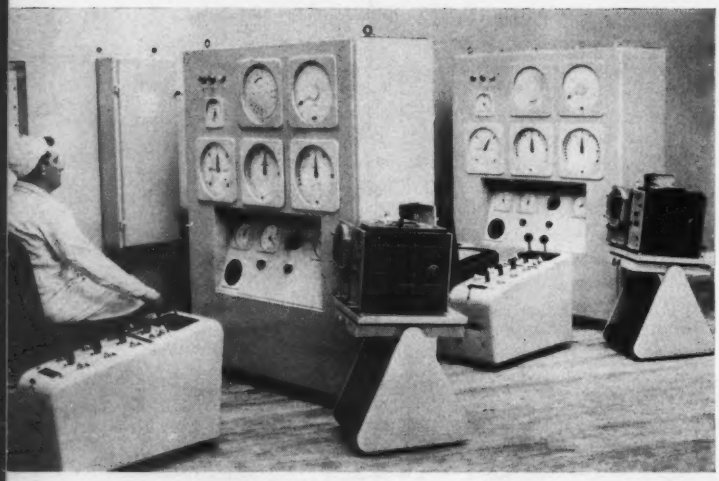
GEC AND APC are to submit a combined tender for the Oldbury CEGB station. This is the first co-operative effort between the two companies since they started negotiating in mid-1959. An agreement was originally concluded in the autumn of that year (*Nuclear Engineering*, November, 1959, p. 381), but the following spring it was announced that the partnership had been dissolved due to difficulties in arranging detailed responsibilities (*Nuclear Engineering*, April, 1960, p. 147). Later, however, they entered into further negotiations, resulting in August, 1960, in the formation of United Power Constructions. Speculation as to the future operation of this company, however, was raised when in October it was announced that GEC and English Electric were negotiating over a possible merger. When nothing came of the negotiations it was still open as to whether GEC and APC would tender either separately or together for Oldbury. Also tendering for this station, which is scheduled for operation in 1966 with a capacity of 550 MW, are the English Electric group and TNPG. Although they have just been awarded the Sizewell contract English Electric are "confident" about the outcome, while TNPG have the advantage of already building a station not far away. On a rotation basis however, GEC and APC would be the winners. Who gets the contract in the end, however, might well resolve on who submits the most attractive design using concrete pressure vessels.

United Kingdom

Extra facilities are to be provided at the Royal Navy's marine propulsion and machinery school at Gosport—H.M.S. *Sultan*—to train ratings for nuclear submarines. All key members of the crew for H.M.S. *Dreadnought* have received special training in the U.S. Crews for the second and subsequent nuclear submarines, however, will receive their training in Britain—officers at Greenwich and ratings at Gosport and on the reactor experiment at Dounreay.

An improved core has been installed in DIDO at Harwell enabling the number of high flux experimental positions to be increased from 27 to 52. It consists of 25 elements each comprising 10 curved U-Al plates supported by inner and outer concentric tubes (*Nuclear Engineering*, Oct. 1958, p.450) and containing 150g U^{235}. Previously the elements were curved plates supported in a rectangular frame. Power level has been increased from 10MW to 13MW. A similar core was installed in DMTR in May.

Hamstead, Isle of Wight, would make an excellent site for a nuclear power station, report the CEGB. Because of its amenity value, however, the Board is deferring any decision about seeking consent for its use. Another possible site, investigated at the same time, was found technically unsuitable. This was at Earnley, Sussex. Soil conditions were found to be unreliable and inadequate for heavy loads and the seabed level was such as to provide insufficient water for cooling purposes.



The control room for the charge/discharge machines in No. 1 reactor at Bradwell. Loading of the reactor is expected to start in May or June.

Deliveries of fuel for the first reactor at Bradwell started mid-December and are expected to continue until May or June.

Finland

Enriched fuel for the Triga to be installed at the Institution of Technical Physics, Otanieme, near Helsinki, is to be delivered by the IAEA free of charge, it was announced at the signing of the contract in Vienna on December 30. The fuel will be supplied by the U.S. AEC and will consist of approximately 13,000 g of 20% enriched U, and 5 g of 90% enriched. Fuel for a sub critical assembly will be supplied by Russia.

France

INSTN, Saclay, is to obtain a 100 kW research and training reactor of the Argonaut type; it will be called Ulysses.

Electricité de France has firmly *decided upon the use of a prestressed concrete pressure vessel for EDF-3, their third reactor to be built at Chinon and due for completion in 1964-65. Its present official rating is 375 MW(e), but the plant is scheduled to include two 250 MW turbo-generators so that an increase in the station's output to 500 MW is anticipated even if this is not achieved with the first core. More complete details of the design will not be known until the important contracts have been placed and until experimental work being conducted on the behaviour of prestressed concrete has been evaluated. In general (apart from the pressure vessel) the design adopted will more closely resemble that of EDF-2 than G2 or G3. The core is to be vertical, with vertical fuel channels and control rods, and steam will be raised in banks of small unit heat exchangers. Fuel will be natural uranium canned in magnesium zirconium alloy. There will be four pairs each of inlet and outlet ducts for the CO_2 coolant, flow being maintained by four circulators.*

Société Industrielle du Zirconium has been formed, on equal shares, between three German, Italian and French groups. The German shareholders are Degussa and Metallgesellschaft A.G., the Italian is Montecatini, and the French Pechiney. The company is to produce zirconium sponge and ingot.

West Germany

Contractual arrangements have been made by Kernkraftwerk Baden-Wurttemberg Planungsgessellschaft (formerly the AKS), of Stuttgart, for a design study of a 150 MW OMR station. The nuclear portion of this study will be undertaken by Atomics International, through its subsidiary, Interatom, and the conventional portion by Brown Boveri and Cie. AG. Cost of the study is estimated at DM4.9 million and it is scheduled for completion within about a year. If a station is built it is hoped it will be in operation by late 1965. Estimated cost of the project is DM260 million. At present it is not certain from where this amount will come, though talk has it that DM110 million will be provided by Euratom (whether as a loan is not clear), DM90 million by KBWP, and DM35 million by ERP. A DM100 million guarantee, it is said, will be given by the Bundes-Ministry of Atomic Energy. Site of the station would be at Obrigheim, near Mosbach/Neckar.

Munich's Institute of Inorganic Chemistry is to build a transuranium chemistry laboratory.

RWE have plans for building a 25 MW BWR or PWR station at Augsburg.

Proposals for a fast reactor power plant, probably to be sited at Karlsruhe, are being discussed by the Bundes Ministry of Atomic Energy and Industry. Nukem have been asked to carry out work on fuel elements for this reactor type.

Fifty-one per cent of Gesellschaft fur Kernenergieverwertung in Schiffbau und Schiffahrt is now state controlled (the West German Bund has 60% of these shares and the Laender 40%). It is understood that Euratom will now certainly participate in the research programme at Geesthacht.

India

Official opening of the 40 MW Canada-India reactor at Bombay by Pandit Nehru took place on January 16. Present at the ceremony were the heads of nuclear energy authorities in the U.K., U.S., U.S.S.R., Canada and France.

Korea

Crates of uranium-zirconium hydride fuel elements are handed over to the Korean consul in San Francisco before being flown to Korea for the Triga reactor now nearing completion at Paktai-ri, about 17 miles South of Seoul.

Israel's Second Reactor

ALTHOUGH tantalizing to the inquisitive engineer (as well as to the Americans), Israel's reticence over the construction of a 24 MW(th) reactor in the Negev is perfectly justifiable. There is no earthly reason why a country should tell the world of its activities, even if they are as harmless and peaceful as Mr. Ben Gurion has assured the Knesset they are in this case. It is generally assumed that the reactor is of French design and is being built with French assistance. If this is the case it might well be an improved version of the EL-3 at Saclay (Ben Gurion has said it is heavy water moderated and uses natural uranium as fuel). Alternatively, it could be based on the Canadian NRX design. All official sources will say is that the reactor is being constructed by Israeli engineers and that they have gained their "know how" from engineers and scientists of many nationalities. On the financial side support could well be coming from France as she has a long-term credit arrangement with Israel. The real facts will probably not be divulged until the reactor is complete, in four or five years' time, and open for the rest of the world to see. Until then we shall probably have to be content with rumours and speculation.

Italy

Energy consumption during the first eight months of 1960 represented an increase of 17.1% over the same period in 1959. It amounted to 39,029,000 tons of coal equivalent.

Japan

Plans have been drawn up by a group of companies for a design study of a nuclear-powered ore carrier to ply between Chile and Japan.

Netherlands

Enriched uranium prepared by the centrifuge process at the F.O.M. Laboratory, Amsterdam, is to be used exclusively for scientific purposes, said the Minister for Education, Arts and Science, recently. He added that international co-operation on the development of the centrifuge method was under consideration.

Norway

A quarter of a million guilders (about £25,000) have been presented to the Reactor Centrum Nederland by the Institutt für Atomenergi, Oslo, for the establishment of a library at Petten.

Pakistan

The 5MW pool-type reactor to be installed at the Institute of Nuclear Science and Technology, near Rawalpindi, will be supplied by A.M.F. The U.S. AEC will contribute £350,000 towards its cost.

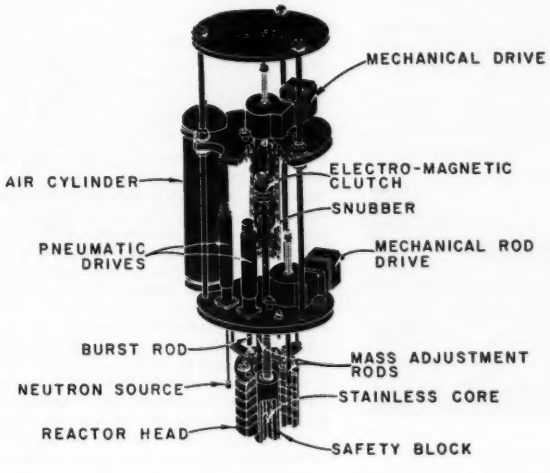
U.A.R.

A power reactor in the Nile Valley is envisaged by the Minister of Education. He hopes that German industry will be interested in providing the plant.

U.S.A.

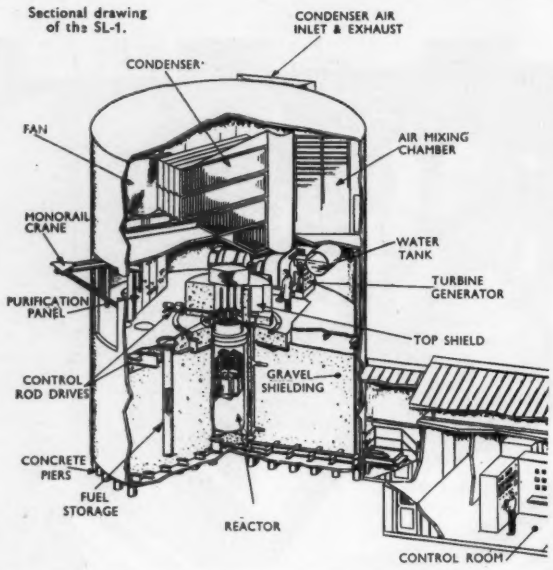
Poland

Full use is made of the 2MW(th) tank reactor, EWA, at the Nuclear Research Institute, Swierk, Warsaw, supplied by the U.S.S.R. It has been in operation since 1959. Shortly, the Institute is to install a graphite-water moderated reactor of Polish origin. EWA is of the Soviet's VVR-S class, other reactors of this type having been supplied to Czechoslovakia, East Germany, Hungary and Yugoslavia. Operating fuel charge is 60kg of U enriched to 10% made up in 500-mm-long aluminium cans. Maximum neutron flux is 2×10^{13} thermal neutron/cm^2 s. Experimental facilities include 9 horizontal channels, 10 vertical channels, a sliding thermal graphite column and 3 special channels for biological research.



The Fast Burst Reactor

CONSTRUCTION of a small research reactor to provide short bursts of radiation for biomedical and health physics research, is scheduled to start at Oak Ridge on April 30. Known as the FBR (Fast Burst Reactor), it will consist mainly of a core of uranium molybdenum alloy without shielding or moderator. Radiation exposure will be very small outside the limited access area. It will be located about two miles from the central ORNL facilities in a hollow surrounded by hills of sufficient height to provide adequate shielding for surrounding areas. Its design provides for a pulse of 40 microseconds consisting of fast neutrons as free as possible of thermal neutrons. In addition, the reactor can be operated under constant, steady state conditions at power levels of up to one kilowatt. Some experiments will be performed inside the reactor building while others requiring additional unobstructed space for certain measurements will be conducted in the open on a concrete apron. The control building will be situated about 800 feet from the reactor, behind a shielding ridge. Design of the FBR facilities is being undertaken by Giffels and Vallet, of Detroit. Completion of the $1,400,000 project is scheduled for April, 1962.



The SL-1 Accident

THE SL-1 in which the fatal accident at Idaho Falls occurred on January 3 is a 200 kW(e) BWR intended as a power source for isolated military locations. Previously known as the ALPR (Argonne Low-Power Reactor), it had been in operation since the autumn of 1958 (a technical description was published in *Nuclear Engineering* in January, 1959). At the time of the accident, it had been shut down for 10 days and the three killed were connecting up the control rods preparatory to a start-up. Two of the men were certificated reactor operators, and the third was due to receive his certificate in February. Preliminary evidence strongly indicated that a nuclear excursion was involved. Whether an explosive chemical reaction took place is not known. Examination of the dead bodies revealed multiple injuries which were severe enough to have caused their deaths. At the same time is was known that the radiation dose present was sufficient to be fatal—the radiation level on the reactor top several days after the accident was as high as 1,000 r/h. Because of the intense radiation, difficulty was encountered in removing the bodies. One of them was lodged in the upper structure of the reactor building and its removal involved 22 men and the slinging of a safety net across the building to prevent it from falling on to the top of the reactor. Outside the containment vessel the radiation levels were as low as 0.5 to 1.0 r/h in the immediate vicinity and less than 0.001 r/h on a nearby public roadway. Concurrently AEC are conducting a safety evaluation survey of all existing licensed reactors.

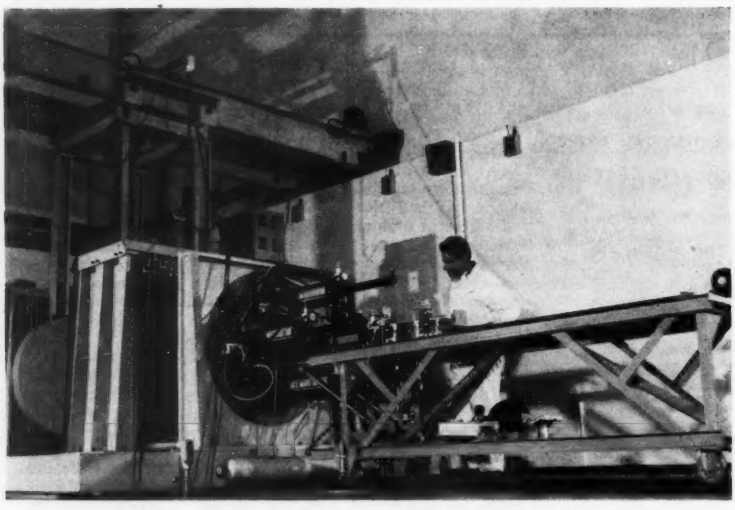
Operational ground tests have been successfully completed on the SNAP Experimental Reactor (SER) developed by Atomics International for use in space vessels. Weighing about 250 lb, it is the prototype for the SNAP-10 power system designed to use a thermoelectric converter and SNAP-2 and -8 systems which will use miniature turbine generators.

NASA are to negotiate with the Ralph M. Parsons Company and the Thiokol Chemical Corporation for a study into the requirements of a National Nuclear Rocket Engine Development Facility. Thiokol are representing "Talant," a group comprising Thiokol, the Allison Division of General Motors, the Linde Company, a division of Union Carbide, and the Nuclear Development Corporation of America.

The 4 MW(th) pool reactor which has been in operation at the Curtiss-Wright Corporation's nuclear centre at Quehenna, Pennsylvania, since 1958, has been given by the company to the Pennsylvania State University, together with associated hot cells and other facilities. The university now owns two reactors, the first one being a 200 kW pool type unit which went critical in 1955.

Utility companies have been invited by the AEC to indicate their willingness and ability to construct and operate a 50 MW(e) OMR plant by 1964. It would serve as a prototype for a 300 WM(e) which could be economic in high fuel cost areas of the U.S.

The Langsdorf Pile Oscillator, designed in 1945 for research work in conjunction with the CP3 at Argonne, has been transferred to the Smithsonian Museum, Washington.



The critical assembly developed by Atomics International for use in the Advanced Epithermal Thorium Reactor (AETR) project. It consists of a square honeycomb structure in two sections. These are brought together by remote control to achieve criticality. Materials to be tested are mounted in the honeycomb partitions.

Access to classified information on gas centrifuges is being offered by the AEC to companies who can demonstrate a serious interest and capability in the design and construction of these machines. The companies will be obliged to meet with the AEC security arrangements and there are several royalty and licensing conditions to fulfil. In the meantime the Commission is continuing its own research and development programme in this field, including basic research at Virginia University and the experimental operation of machines at Oak Ridge.

Oak Ridge should begin to consider areas of endeavour outside the nuclear energy field, suggested Dr. A. M. Weinberg, ORNL director, in his annual "state of the laboratory" speech. He stressed, however, that such problems as desalination of sea water, oceanographic research, or the chemical contamination of the biosphere should not be allowed to divert Oak Ridge from its primary mission.

Because of faulty material and staffing problems construction of the 60 MW(th) tank type reactor by the National Aeronautics and Space Administration at Plum Brook, Sandusky, Ohio, has been delayed. As a consequence the AEC has extended the construction licence to January 1, 1962. This is the second extension granted. The licence was issued in 1958 and originally expired on January 1, 1960. Later, 12 months were added on. In November, 1960, NASA reported that additional work was required on the surface of the reactor tank to eliminate microscopic imperfections which had been rolled into the surface in the fabricator's plant, additional work on piping attached to the reactor tank was necessary, a vent line had to be added, a fuel storage alarm had to be installed and there were difficulties in recruiting certain key qualified staff. Nevertheless, NASA hope during 1961 to operate the reactor, which is designed for materials testing, at levels up to 100 kW and have asked for a provisional operating licence for this purpose.

General Electric are to build, in conjunction with Empire State Atomic Development Associates, of New York, a superheat developmental reactor for the purpose of extending the technology of nuclear superheat for eventual application to large-scale power plants. ESADA will contribute $5,750,000 towards the total cost of $8M. This is additional to their participation in the HTGR development programme to be undertaken by General Atomic (*Nuclear Engineering*, January, 1961).

Nearing completion at Argonne is the Juggernaut, a stepped-up version of the Argonaut research and training reactor. With an operating power of 250 kW, it will be used for developing nuclear instruments and in analytical chemistry and electronics research.

With the ending of the Eisenhower presidency Mr. John McCone is relinquishing his post as chairman of the AEC, which he has held since 1958. At the time of going to press his successor had not been appointed, but chief among the names which have been bandied about is that of Mr. Robert McKinney, of the McKinney reports fame and for a short time U.S. representative at the IAEA. Recently he has been chairman of the Joint Congressional Committee on Atomic Energy and has been very critical of some of the AEC's policies.

Four amendments have been made to the AEC regulations on radiation protection. As a result of the first one, three-month calendar quarters can now start on any date in January, April, July or October, rather than only on the first of the month. Also, calendar months which are determined on a weekly basis can consist of alternating 14-week and 12-week periods rather than only 13-week periods. The second amendment refers to the posting of licensing notices where employees can see them on the way to and from work rather than in every establishment where licensed activities are being carried on regardless of whether there are any restricted areas in the establishment which require radiation protection control measures. The definition of the term "Restricted Area" has been amended so that it is now more precise; a corresponding redefinition has been made of "Unrestricted Area." The fourth amendment comprises an additional specification to the permissible concentration limits of radionuclides in uranium ore dust.

A public hearing is being held on February 1 into the safety aspects of the N.S. *Savannah*. All facts relating to the nuclear safety of the ship during starting-up, testing and sea trials are being placed on public record as well as the testimony of designers, builders and safety experts connected with the project.

U.S.S.R.

The first 70 MW turbine for the PWR station under construction in the Voronezh region has been installed. Two more will be installed later this year when the first of the two reactors is expected to be completed. Ultimate capacity of this station is 420 MW(e).

Forum

Sir,

The Editorial in your December issue on the case for a U.K. Forum is timely, both for home and abroad.

I must agree with you that at home the picture is greatly confused; the monopolies are in too dictatorial a position (however benevolent their intentions) for their own good and for the health of the nuclear industry.

The large consortia have been obliged to defer to the Authority for their bread and butter. Now that only three remain they probably need no longer do so, but their vested interests in large gas-cooled graphite reactors may mean that their great influence will still be directed towards concentration on this type to the neglect of all else, as was demonstrated by the late Sir Claude Gibb's speech at the FBI Conference at Eastbourne.

The meetings of the BNEC have naturally been dominated by the exponents of Calder Hall and its successors who, alone in this country, have been able to proceed from paper to bricks resulting in such exercises as Hinton and Moore's paper on marine reactors at the Institute of Marine Engineers.

An informed body of opinion from industry to confer and, when necessary, to oppose the monopolies is much needed. The difficulty will be to find men of stature, nuclear knowledge and experience, who are in sufficiently independent positions to discuss problems on a national basis in the open. Judging by the discussions at BNEC meetings, they are few. A forum that merely rubber-stamps existing policy will be worse than useless. If a strong forum is formed, it could, at home, advise Lord Hailsham on all nuclear developments and, abroad, it could represent this country with the Commission Euratom de l'Unice.

As you rightly say, the British public worries little about the radiation hazards from nuclear power but another accident with more serious consequences might possibly happen one day and we should be ready to deal with such an event. Other countries, particularly Germany, are more "windy" and we shall have to persuade their people that our nuclear ships are not dangerous. The British forum could do this and also be a constituent of Foratom.

CAPTAIN H. F. ATKINS.

U.S. AIF President's Statement

FRANCIS K. McCUNE, president of the U.S. Atomic Industrial Forum, recently drew the attention of AIF members to some of the more significant signposts in the nuclear industry.

Mr. McCune, who is also General Electric vice-president for engineering services, said the establishment of a joint AEC-NASA office to manage the nuclear rocket programme and the expressed intention of this office to select a contractor to provide engineering support and conduct R&D on a nuclear rocket engine "are worthy of note."

Commenting on nuclear power for merchant ships, Mr. McCune said that he is encouraged because "the world is now moving from paper studies into the hardware phase of the business."

In discussing the transition from Government to private activity in many atomic fields, the General Electric vice-president pointed to the area of research and development as one of the most critical problems.

He reported that the Atomic Energy Commission is continuing to put the major portion of its research and development dollars into their own programmes. "The Government owned laboratories are still growing," he pointed out, "yet the ever present possibility that weapons work will diminish could drain the AEC R&D till dry in an effort to sustain these laboratories at their present level of operation." Another factor for industry consideration, he said, is the potential limit on future atomic appropriations due to shifting the attention of Congress from atomic energy to more pressing space programmes.

He cited another problem for industry in the present licensing practices of Government. To date, he said, licensing procedures have been permissive rather than "truly regulatory." "As we progress in this business and the technology becomes more stable, it is the industry's responsibility to develop the common safety standards which can be applied to design specifications and operational procedures and to have these standards accepted by the governmental regulatory agency. "Only then," he stated, "will we be able to shed the cumbersome process of obtaining prior approval from the AEC for the construction and operation of nuclear power installations."

Already, he said, the AIF has directed considerable attention to the problems facing industry, and has proved itself as a capable spokesman. In this rôle the AIF is paying more and more attention to the problems of adequate public understanding of nuclear development.

The date of the first meeting convened by the FBI nuclear conference committee to discuss whether the U.K. should join Foratom has not yet been announced. *Nuclear Engineering* understands that it will probably take place in March. Invitations will be sent to "all interested parties" by the president of the FBI. It appears that initially the meeting will be solely concerned with the Foratom question and that, for the time being, the decision to establish a U.K. Forum will depend on the reaction at the preliminary meeting.

Forming the Canadian Nuclear Association

A YEAR ago a steering committee was formed to look into the prospects of founding a Canadian association to help promote the peaceful uses of atomic energy in Canada. Members of several organizations engaged in some aspect of nuclear activity had been individually considering this for some time, and their ideas were brought into focus at the First Canadian Conference on Uranium and Atomic Energy held in Toronto in November, 1959. The sponsor of this conference—Ontario Minister of Energy Resources, Robert Macaulay—personally supported in his summing-up speech the need for an organization in Canada similar to the atomic forums which had been formed in the U.S., Western Europe and Japan.

The steering committee first of all explored the potential membership for such an organization by means of a letter to several hundred organizations inviting expressions of interest. This "market research" was considered necessary, since the application of nuclear energy in Canada was still considered to be at an introductory stage, with the first 20-MW prototype nuclear power reactor not due for completion until late in 1961. The steering committee noted that the only other power reactor then planned in the country was the 200 MW, $80 million CANDU plant to be installed by 1965 at Douglas Point near Kincardine on the shores of Lake Huron, Ontario. It was thought Canada's nuclear effort to date had been noteworthy not through the extent of its practical utilization for power purposes as in, for example, the U.K., but rather through the excellence of its research work at Chalk River on the heavy-water type of reactor. With the Hydro Electric Power Commission of Ontario alone planning the installation of over 6,000 MW of nuclear power by 1980 the prospects for increased nuclear development in the next few years were considered excellent. However, in view of the limited amount of work done by nuclear firms up to 1959, and the fact that existing plans for the large-scale construction of nuclear plants would begin some years hence, it was thought to be a good idea to have this "market survey" to ensure that there was sufficient potential support for the association to be commenced immediately.

The response to the steering committee's inquiry letter was good, with close to 200 organizations expressing interest in joining the association "if, as, and when formed." On this evidence, which was obtained by mid-year, the steering committee took immediate steps to form a Board of Directors composed of senior representatives of organizations which were, or expected shortly to be, engaged in some phase of the development and/or utilization of nuclear energy. It was regarded as essential to have representatives from all areas of the country. The first board presently consists of the senior representatives of Canadian organizations shown below, and will stay in office until the second annual meeting to ensure continuity.

Mr. R. F. Gross has now been appointed general manager and took office at the beginning of this year. More staff will gradually be taken on as the association grows in importance and as the Canadian nuclear industry expands.

One of the key problems when the association was being formed was whether the work which the association would do could in fact be done by other associations such as the Canadian Manufacturers' Association, the Canadian Electrical Manufacturers' Association, the Canadian Underwriters' Association and others. Some of these organizations had already done some work in this field; for example, the Underwriters' Association had seconded an official to help form a Nuclear Insurance Association of Canada. The C.M.A. also had a group looking at this.

C.N.A. BOARD

President:
Mr. I. F. McRae, Chairman of the Board, Canadian General Electric Company, Ltd., Toronto, Ontario.

Vice-President:
Honourable Robert W. Macaulay, Ontario Minister of Energy Resources and Vice-Chairman of Hydro-Electric Power Commission of Ontario, Toronto, Ontario.

Directors:
Mr. B. A. Avery, Vice-President, Orenda Engines, Ltd., Malton, Ontario.
Mr. S. M. Blair, President Canadian Bechtel Ltd., Toronto, Ontario.
Mr. W.M. Gilchrist, President, Eldorado Mining & Refining Ltd., Ottawa, Ontario.
Mr. A. E. Grauer, Chairman, British Columbia Electric Company Ltd., Vancouver, B.C.
Honourable Donald Harper, Chairman, New Brunswick Electric Power Commission, Fredericton, New Brunswick.
Mr. Jean-Claude Lessard, President, Quebec Hydro Electric Commission, Montreal, Quebec.
Mr. W. R. McLachlan, Vice-President, Canadian Westinghouse Company Ltd., Hamilton, Ontario.
Mr. Stephen B. Roman, President, Denison Mines Ltd., Toronto, Ontario.
Mr. G. I. Staber, General Manager, AMF Atomics Canada Ltd., Port Hope, Ontario.
Mr. D. M. Stephens, Chairman and General Manager, The Manitoba Hydro-Electric Board, Winnipeg 1, Manitoba.
Honourable Robert H. Winters, President, The Rio Tinto Mining Company of Canada Ltd., Toronto, Ontario.
Dr. J. W. T. Spinks, President, University of Saskatchewan, Saskatoon, Saskatchewan.

Two main objections were considered decisive against allowing these organizations to expand their nuclear activities into the vacuum which existed. One was the danger of duplication or even triplication or worse which would exist without a co-ordination of effort. Second, all of these organizations had to take into account factors which would tend to deter rather than encourage nuclear development. For example, one association had members who were manufacturing for coal-fired thermal power stations, and their interests could be adversely affected by an increase in the nuclear programme. These associations would, therefore, have to tread very cautiously in helping promote nuclear energy; indeed, this could not be done at all if the interests of those of their members antagonistic to nuclear power were to be safeguarded. In insurance too, there was a danger of inadequate representation. The interests of, say, the manufacturers in nuclear liability would be for the lowest possible rates, whereas an association representing the underwriting companies might be prepared to hold out for fairly high rates.

The naming of the association was given much thought. It was decided there was not really room at present in Canada for a technical society like the American Nuclear Society as well as a management group like the Atomic Industrial Forum. The Canadian organization would be primarily a management group but would also hope to carry out some of the functions of the technical group. The name Canadian Nuclear Association was approved bearing in mind these factors.

The C.N.A. hopes to have close connections with the atomic forums of other countries and would welcome particularly a liaison with a U.K. Forum should this be formed.

The C.N.A.'s objectives are summed up as follows:—

1. Promote and foster an environment favourable to the healthy growth of the peaceful uses of nuclear energy and radio-isotopes.
2. Encourage co-operation between various industries, utilities, educational institutions, government departments and agencies, and other authoritative bodies which have a common interest in the development of economic nuclear power and uses of radio-isotopes.
3. Provide a forum for the discussion and resolution of problems which are of concern to the members, to the industry or to the Canadian public generally.
4. Stimulate co-operation with other associations that have similar objectives and purposes.

Like other atomic forums, the C.N.A. plans to set up committees of members to examine and report on various problems in the nuclear field and is already conducting a survey of nuclear education in Canada. The C.N.A. will also provide a means of liaison between industry and government, will publish a journal on nuclear developments for members and will sponsor conferences on nuclear energy. The first annual meeting and conference of the association will be held in Toronto on May 16-17, this year. Full details of the conference or of the association generally, may be obtained from the General Manager, Box 475, Adelaide Street Postal Station, Toronto, Canada. Representatives attending the conference from the U.K. will be particularly welcome.

J. E. Hore

(Rio Tinto Mining Co., who has been acting as secretary of the C.N.A. during its formative stages.)

Maximum Permissible Levels

AS the result of a request by the Prime Minister to the Medical Research Council in early 1955, an independent Committee was established to report on the medical and genetic aspects of nuclear radiation. Its first report was produced in June, 1956, and now in the light of subsequent research and the recommendations of the International Commission on Radiological Protection a second report has been published as Cmnd. 1225. (The Hazards to Man of Nuclear and Allied Radiation, a Second Report to the Medical Research Council, H.M.S.O., 7s.)

Before outlining the maximum permissible levels that are now to form the basis for operational practice it would seem appropriate to recall the units of measurement that are internationally accepted. The unit of radioactivity is the curie, defined as a distintegration rate of 3.7×10^{10} disintegrations per second; the amount of radiation actually absorbed in tissue is measured in rads, one rad corresponding to 100 erg energy per gram of tissue. The roentgen is a unit of dose applicable to measurements in air, one roentgen (r) being the amount able to produce in 0.0013 g air, ions carrying 1e.s.u. of charge. It is roughly equal to the rad when applied to soft tissue. In order to take into account the variation in the biological effects of different types of radiation the rem (roentgen equivalent for man) has been devised which includes an additional factor—the relative biological efficiency (r.b.e.). One rem therefore equals one rad multiplied by the r.b.e. of the radiation which for beta, gamma and X radiation is normally unity but for alpha radiation is equal to 10.

The maximum permissible levels now recommended do not differ greatly from the 1956 report and closely resemble the recommendations of the ICRP which were adopted in September, 1958, and extended in 1959, but certain additional provisos have been added.

Occupational Exposure

For workers occupationally exposed to radiation these are as follows; it should be noted that for establishing general working conditions and checking doses by film badges it is the first of these that applies.

3 rem during any period of 13 consecutive weeks to the gonads, the blood-forming organs and the lenses of the eye, at any age over 18 years.

20 rem during any period of 13 consecutive weeks to the non-critical portions of the body. Annual dose not to exceed 75 rem.

235 rem of whole body radiation for persons exposed from the age of 18 to 65. This corresponds to the formula that the dosage $D=5\ (N\text{-}18)$ where N is the age of the person in years.

60 rem to the gonads by age 30 which corresponds to the formula appropriate to paragraph two.

The committee while approving the changes implied above does add the proviso that the contribution to the genetic dose of the whole population must not exceed 1 rem per head of population (by the age of 30). For persons below the age of 18 years whereas the Commission is prepared to accept a dose of 5 rem in any one year the Committee is of the opinion that for persons between the ages of 16 and 18, occupationally exposed, their dose should not exceed 1.5 rem in any one year; the limit of 60 rem by age 30 still applies. The Committee approves the later interpretation of the 13-week period that ICRP now accepts whereby a calendar 13-week period is satisfactory instead of any 13 consecutive weeks where there is no reason to suppose that doses are being accumulated at grossly irregular rates.

Special Groups

The Committee also accepts that certain fractions of the population who are not occupationally exposed may be permitted to receive doses in excess of those generally received by the population at large; the recommendations for these classes of people are as follows:

Adults working in the vicinity of areas within which radiological supervision of the workers is required or who enter such areas occasionally in the course of their duties but are not regarded as radiation workers, for radiation involving specifically the gonads or the whole body, 1.5 rem/an.

Members of the general public including children living in the neighbourhood of these special areas, for radiation in the same class as that described above, 0.5 rem/an.

Limited numbers of individual members of the population of the country as a whole, 0.5 rem/an.

The maximum integrated dose received by the age of 30 would then be 18 rem for the adults only class and 15 rem total by the age of 30 where children may be exposed from birth. These figures can be compared with an average of 5 rem by the age of 30 for the general population as a whole which is the ICRP's most recent limit.

Population Levels

With this 5 rem limit the Committee agrees but stresses that the dose from any particular source should be kept as low as practicable and assessed in relation to that source. The figures refer to artificial sources excluding medical radiology.

For comparison the average levels of background radiation that have been deduced following extensive measurements in various places over the earth's surface are quoted. For this country an average figure of 100 mrem/an is sufficiently close to the one established to be used as a working basis. The spread however in actual figures is large and dwarfs any artificial contribution from general effects such as fall-out, use of luminized wrist watches, etc., and is also greater than the average medical dose. Irradiation from a natural source occurs in two ways, externally and internally. The external radiation depends markedly on the locality, the mean dose rate out-of-doors in Aberdeen, for example (104 mrad) being twice that in Edinburgh. Overseas the spread is much larger varying from 50 mrad in places over sedimentary rocks to about 200 mrad/an in granite districts; in one state of India dose rates of up to 4,000 mrad/an have been recorded. Cosmic rays contribute another 24 mrad/an. Internal radiation is dominated by the potassium-40 content of the body and this contribution is estimated to be about 20 mrad/an. Combining these figures an average dose of 100 mrad/an is received in the United Kingdom with a spread of at least 20 mrad. The only significant additional contribution from man-made sources stems from general diagnostic radiology which is calculated to give an annual genetically effective dose of 19 mrad. For the record, however, fall-out is contributing an additional 1.2 mrad/an and the increase in the average population level resulting from all the occupational exposures in atomic energy establishments and factories is 0.5 mrad.

Emergency Levels

The following total doses of radiation are considered acceptable for members of the general public as a result of an incident at an atomic energy establishment. They are to be considered as independent of the duration of the irradiation:—

1. The dose of gamma rays giving exposure to the whole body but measured in free air: Children up to the age of 16 years and pregnant women, 20 r; other persons, 30 r.

2. Subject to (1) above, the combined dose of beta and gamma rays giving exposure to the whole body surface and estimated in any superficial tissue: Children under the age of 16 years, 75 rad; other persons, 150 rad.

3. For small areas of contaminated skin in total not greater than 1/10 of the body surface, doses from beta rays averaged over 1 cm^2 additional to those specified in (2) above: Children up to the age of 16 years, 75 rad; other persons, 150 rad.

4. In order to allow essential duties to be performed, a special category of a few persons is envisaged, consisting of adult males (preferably in the older age groups) or of females above reproductive age. For this group, a dose of gamma rays giving exposure to the whole body but measured in free air, additional to (1), (2) and (3) above, 30 r.

The 15 MW BWR at Kahl

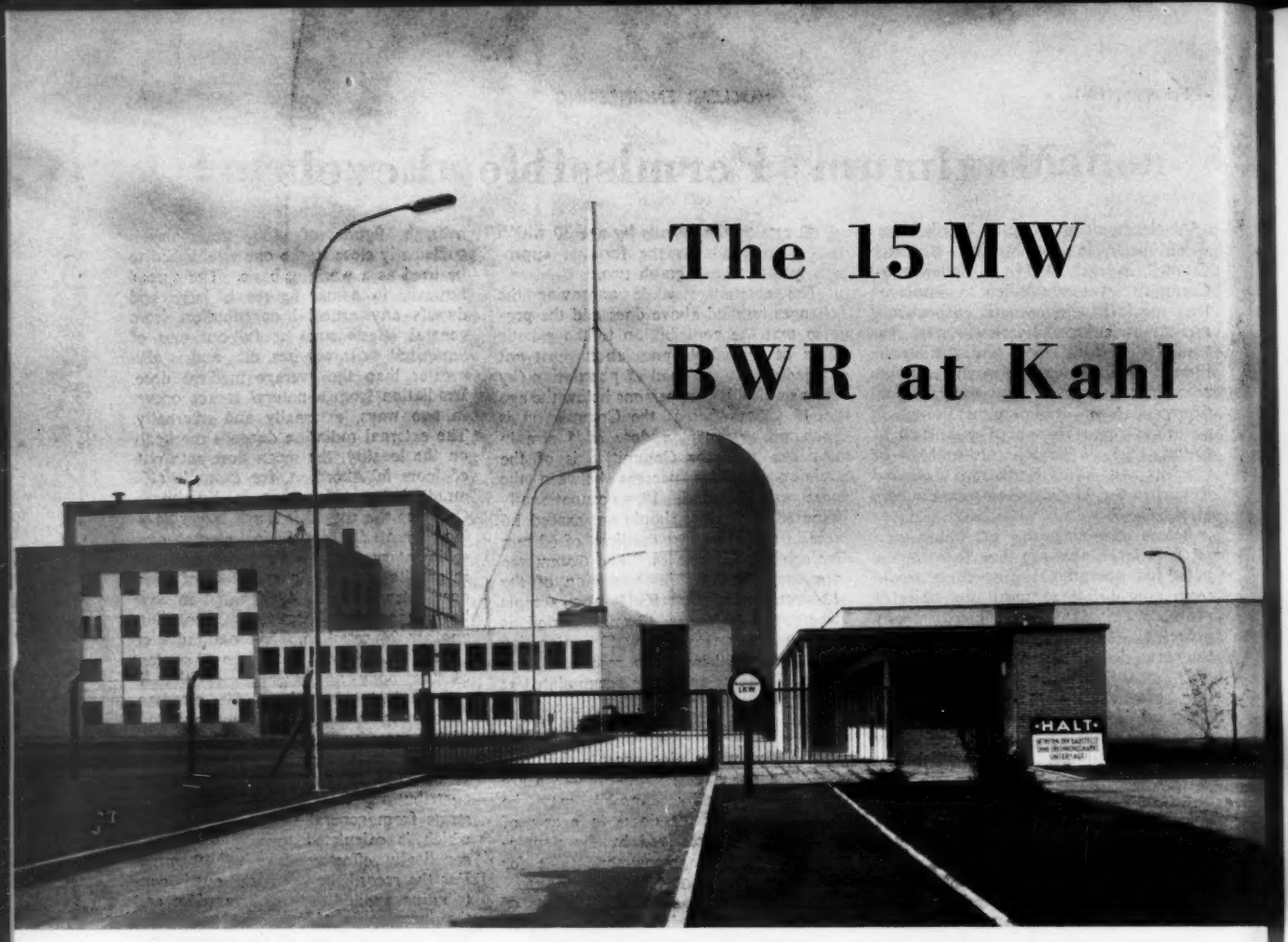


Fig. 1.—The Kahl reactor.

Description of the Plant

by **R. KÜHNEL** (*Atomic Energy Division, AEG*)

ON June 13, 1958, the Rheinisch-Westfalische Elektrizitatswerk AG (RWE) placed an order for the construction of the first German nuclear power station at Kahl/Main. The purpose of the station—apart from electrical generation—was to test the operational safety of a boiling water reactor for public energy supply, to provide facilities for the training of personnel for large stations and to clarify a number of problems such as control response, power limits, suitability of materials, etc. RWE appointed as their main supplier Allgemeine Elektricitatsgesellschaft AEG in Frankfurt/Main; this company was given full responsibility for the complete construction of the power station. RWE subsequently formed a contracting company known as Versuchsatomkraftwerk Kahl GmbH with 80% of the capital belonging to RWE and 20% to Bayernwerk AG, Munich.

The construction programme called for the completion of the reactor, turbine plant and operations buildings by May, 1959, and the process plant, waste storage, coolant inlet and discharge installations by September, 1959. Instrumentation, pipe runs and also the electrotechnical work were to be finished by April, 1960, and the turbo-generator was to be ready for operation not later than August, 1960. The first pre-operations tests were scheduled to start after completion of erection in May, 1960, followed by fuel loading and the zero-energy tests and finally power tests. The station, after operating for one month, was to be handed over to the customer on December 15, 1960.

As the station was to be erected on the dumping site of a former lignite working, compaction of the soil was required because of the poor condition of the ground. This was to be especially thorough under the reactor and the turbine base. The reactor building is supported by a concrete caisson, the bottom of the building being approximately 25 m below ground level. At the processing plant ground conditions were so bad that a foundation on piles was necessary.

The whole of the steam generating plant is housed in the reactor building. The cylindrical containment shell, 13.7 m dia. and 32.3 m in height over the barrel, is welded from 102 steel plates, of thickness 21 mm in the barrel, and 12 mm in the spherical part inside the caisson. The caisson itself, the interior structure and the 70-cm-thick annulus placed above ground level around the containment shell as a radiation shield are of reinforced concrete. The building has been insulated against subsoil water by means of bituminized board inside the caisson although the caisson was already watertight on its own account.

For the normal admission of persons through the reactor pressure shell, a personnel lock is provided connected to the operations building. An additional emergency lock permits three men to pass through together. For changing fuel there is a materials lock which provides a connection between the reactor building and the processing plant. The personnel and the emergency locks are designed

Principal Sub-contractors

General Electric Company APED, San Jose, Calif. (through IGE). Supply of fuel elements, control rods and control gear with auxiliaries, various ancillary equipment for the reactor pressure vessel, measuring and control installations; design and construction of the nuclear steam generating plant; the training of operating personnel.

Hochtief-AG fur Hoch-und Tiegbauten, vormals Gebr. Helfmann. (Erection of all buildings including the containment vessel, all earth work; various ancillary services.)

Mannesmann-AG, Dusseldorf. (Construction of the reactor pressure vessel.)

Mannesmann Rohrieitungsbau. (Supply and erection of all pipe lines for the nuclear steam plant.)

Gutehoffnungshutte, Oberhausen-Sterkrade. (Construction of the heat exchanger and various work relating to the erection of large vessels.)

Vereinigte Kesselwerke, Dusseldorf. (Construction and installation of the sub-coolers.)

for the full pressure of the containment shell (6.05 atm), while the materials lock only for the smaller pressure which might arise as the result of an accident during fuel changing (0.35 atm).

The foundations of the turbine building were effected by compression in depth of the ground by a vibrational method. The foundations consist of steel reinforced concrete; the upper steel reinforced concrete structure is filled in with brickwork.

The roof insulation in all buildings consists of several layers of bituminized board and cork.

The operations building which contains in its first part the main control-room, with its complete switching gear, d.c. supplies, etc., and in its second part the laboratories, air conditioning plant and various offices, is a steel reinforced concrete structure filled in with brickwork. Here too compression of the soil was effected by a vibrational method. The process building contains mainly the purification plant with its auxiliary control-room, the storage areas for irradiated and new fuel elements, and the discharge plant for the air from the reactor building. In addition there are in this building parts of the gas discharge plant, the intermediate coolant circuit and the heating and ventilation installation for the building. Part of the emergency coolant plant for the reactor building is also installed here. The foundations of the building are carried on pillars with additional vibration in depth while filling in gravel to limit the length of the piles. The foundations and the upper structure are made of steel reinforced concrete. The base of the process building is insulated against subsoil water by means of several layers of bituminized board.

The dumps for solid and liquid wastes are of steel reinforced concrete, as are also the inlet building, which contains the main coolant water pump, and the discharge building.

The entrances to the reactor building, process building and to the dumps for solid and liquid waste materials had to be positioned to meet official requirements that in case of high water in the river no water could enter the building.

Nuclear Steam Generating Plant

The reactor installed in the power station at Kahl is a natural circulation indirect cycle BWR feeding steam to a heat exchanger. The separated reactor water mixes with the condensate flowing back from the heat exchanger and sub-cooler and passes down through the downcorner around the core, between the control-rod guide tubes back into the core. The primary steam with a wet steam pressure of 71 atm abs. condenses in the heat exchanger the condensate flowing back to a sub-cooler and thence to the reactor (Fig. 7).

The natural circulation in the reactor is assisted by the sub-cooled primary condensate fed through a return sparger as well as by risers above the reactor core. The sub-cooled condensate shifts the boiling point in the reactor core upwards which reduces the mean steam content in the core and permits a higher power density.

The secondary condensate is fed via a sub-cooler into the heat exchanger through a return sparger to which is also added water from the water-steam separation. At the upper end of the boiler tubes is a steam-water separator, further drying of the secondary steam being effected higher up in the heat exchanger in a separate fine separator. The quality of the secondary steam flowing to the turbine should not be less than 99.8% (0.2% wetness).

Fuel Elements and Reactor Core

The fuel for the experimental nuclear power station at Kahl is enriched uranium dioxide. Sintered pellets 12.7 mm mean diameter and 16 mm in length are ground on their cylindrical surface and enclosed in Zircaloy sheaths of wall thickness approx. 0.85 mm. A single fuel rod contains 48 UO_2 pellets and has a length of approx. 760 mm; 72 such fuel rods make up one fuel element in which two layers of rods are combined in a 6 x 6 arrangement. The fuel rods are held at their lower ends in a grid plate specially shaped to ease the flow of cooling water, and this is fixed to the lower core lattice plate. At the upper end there is a similar grid plate for securing the 36 fuel rods to the upper core lattice plate. For carrying the fuel element, a handle is provided at the upper grid plate level.

The connection between the upper and lower fuel rods is effected by a guide plate at about the middle of the fuel elements with appropriate apertures for the passage of the coolant. The guide plate determines the position of the rods in relation to one another.

At the end of each fuel rod there is a pellet of UO_2 mixed with dysprosium oxide Dy_2O_3 in order to reduce the hot spot factor at these points caused by excess moderator.

The fuel element is enclosed in a square casing approximately 122 mm inside, made of Zircaloy or boride steel, which is readily removable.

The whole reactor core is composed of 88 fuel elements

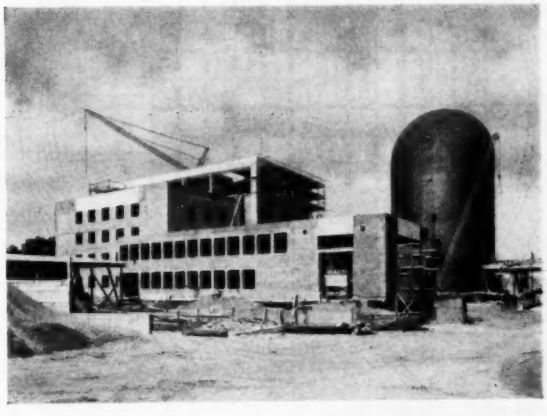


Fig. 2.—Progress during construction. This photograph was taken in August, 1959.

so that the mean core diameter is approximately 1.45 m. Four fuel elements form, together with a cruciform shaped control rod, one cell. These cells of four form a lattice of 5 x 5, with the corner cells replaced by one fuel element.

For the initial charging of the reactor core fuel elements of different enrichment were used to obtain a sufficiently high burn-up in the start-up cycle. The higher enrichment as compared with the normal core made it necessary to employ steel casings with borided steel on one side only (approximately 0.2%B) so orientated that the two borided sides are turned away from the control rods and thus form the exterior of the cells of four. If the reactor is divided into four zones then the first charge appears as follows:—

Zone	Enrichment	Number of elements
1 (inner)	2.3%	4 x 4 steel casings
2	2.6%	22 steel
3	2.6%	22 steel
4	2.3%	28 Zircaloy

At a later time different zones are to be discharged and recharged so that by the third charging a balanced burn-up should be reached.

The infinite multiplication factor of the lattice for the cold uncontaminated core at the starting stage is: $k_\infty = 1{,}32$ and at equilibrium $k_\infty = 1.20$. The effective multiplication factor for the cold uncontaminated core with steel casings is on start-up $k^{\text{eff}} = 1.25$ and at equilibrium $k^{\text{eff}} = 1.13$.

The above mentioned reactivity values are composed as follows:—

Reactivity to compensate for the temperature effects, void and Döppler effects :—on start-up $\Delta k = 0.035$
at equilibrium $\Delta k = 0.035$

Reactivity to compensate for xenon and samarium poisoning :—on start-up $\Delta k = 0.035$
at equilibrium $\Delta k = 0.035$

Reactivity to compensate for a burn-up of approximately 8,800 MWd/t :—on start-up $\Delta k = 0.180$
at equilibrium $\Delta k = 0.060$

The total surface of all fuel elements is approx. 220 m². For a power output of 16 MW at the generator terminals

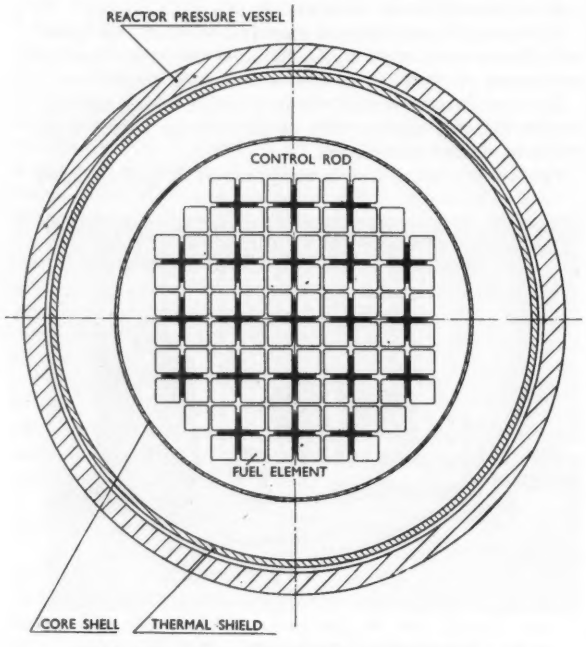


Fig. 3.—Cross-section through the reactor core

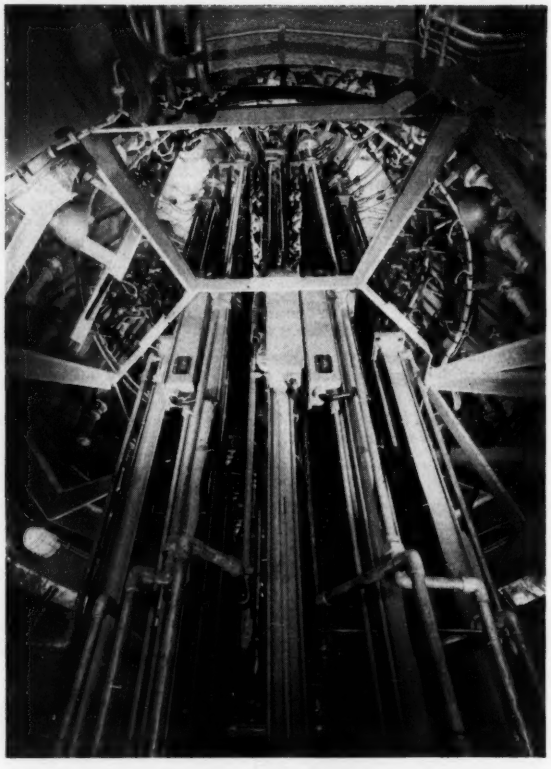


Fig. 4.—View of the control rod drives from below. At the top are the water-lock seals. The lower part comprises the compressed air cylinders and drive motors.

corresponding to a secondary steam volume of approx. 99 t/h, a reactor output of approx. 57 MW(th) is required taking into account the various heat loads such as primary cleaning system, exhaust plant, heat exchanger sludge removing, etc. This means an average heating surface load of approx. 236,000 kcal/m² and an average volume load of the core of 24 kW/l core content. If the total hot spot factor for the first core is assumed to be 4.2 which includes axial as well as radial and local excess flux, a greatest heating surface load of approx. 10^6 kcal/m² is obtained.

The average steam content at the outlet of the core risers is at full load about 6.9% by weight at a total coolant flow of approx. 1,900 t/h. The average burn-up was guaranteed to be 8,800 MWd/t and the metallurgical life of the fuel elements 11,000 MWd/t.

Control Rod Drives

The control rods are inserted at the Kahl reactor into the core from below against the pressure in the reactor pressure vessel. They are connected to the control rod drives by means of an extension shaft and a drive rod through the control rod gland which is constructed as a water lock seal. The control rod drive is composed in the main of an upper part containing the mechanical gear and a lower part containing the pneumatic drive mechanism (Fig. 4).

The drive rod rigidly coupled to the control rod is supported on a nut carriage by means of a latch arm and is guided by two plain shafts. The nut carriage itself carries two threaded nuts supported by two lead screws which if rotated change its vertical adjustment. The screws are rotated by an electric motor mounted in the lower part of the control rod drive through a cardan shaft and a chain

Kahl 15 MW(e) BWR Main Details

Location	Kahl (Main), Germany
Owner	Rheinisch-Westfälische Elektrizitätswerke AG
Main contractor	Allgemeine Elektricitäts-Gesellschaft
Reactor engineering	General Electric APED, U.S.A.
Purpose	Power generation, training, experience
Power	
Guaranteed net	15 MW(e)
Initial gross	16 MW(e) 57 MW(th)
Type	Indirect cycle BWR
Status	Critical, Nov. 13, 1960
Fuel	UO_2
Enrichment	2.3—2.6%
Pellet dia.	12.7 mm, 0.50 in
Pellet length	16 mm, 0.63 in
Pellets/rod	48
Rod length	760 mm, 29.9 in
Rods/element	72
Element casing	Zircaloy/borided steel
Casing section	square, side 122 mm, 4.8 in
Elements/core	88
Total charge, U	5,545 kg
Core:	
Mean dia.	1.45 m, 57 in
Active core height	1.58 m, 62 in
k_∞ (cold, clean)	1.32
k_{eff} (equ.)	1.13
Burn-up	8,000 MWd/t
Mean flux, thermal	1.5×10^{13} n/cm²s
Control rods	Cruciform shape
Number	21
Material	2% borided stainless steel
Primary coolant:	
Pressure	74 atm, 1,000 psig
Sat. temp.	286°C
Flow	1,900 t/h
Max. steam voidage	6.9 w/o
Mean power density in core	24 kW/l
Max. power density	100 kW/l
Mean heat transfer, elements	236,000 kcal/m²
Secondary coolant:	
Flow	90 t/h
Quality	<0.2% wetness
At full power:	
Steam pressure	47.5 atm, 675 psi
Steam temp.	260°C
Feed water temp.	187°C
At zero power:	
Steam pressure	71 atm, 1,000 psi
Steam temp.	286°C
Feed water temp.	158°C
Reactor pressure vessel	Cylinder, domed ends
Overall height	8.45 m, 27 ft 9 in
Internal dia.	2.44 m, 8 ft
Wall thickness	101 mm, 4 in
Cladding	6.5 mm, 0.25 in
Containment vessel	Cylinder, domed ends
Height of vessel	32.3 m, 106 ft
Dia.	13.7 m, 45 ft
Thickness	21/12 mm, 0.83/0.47 in
Pressure test	6.8 atm, 100 psi
Turbine	Single cylinder, single flow
Rating	20 MVA
Output	6.3 kV

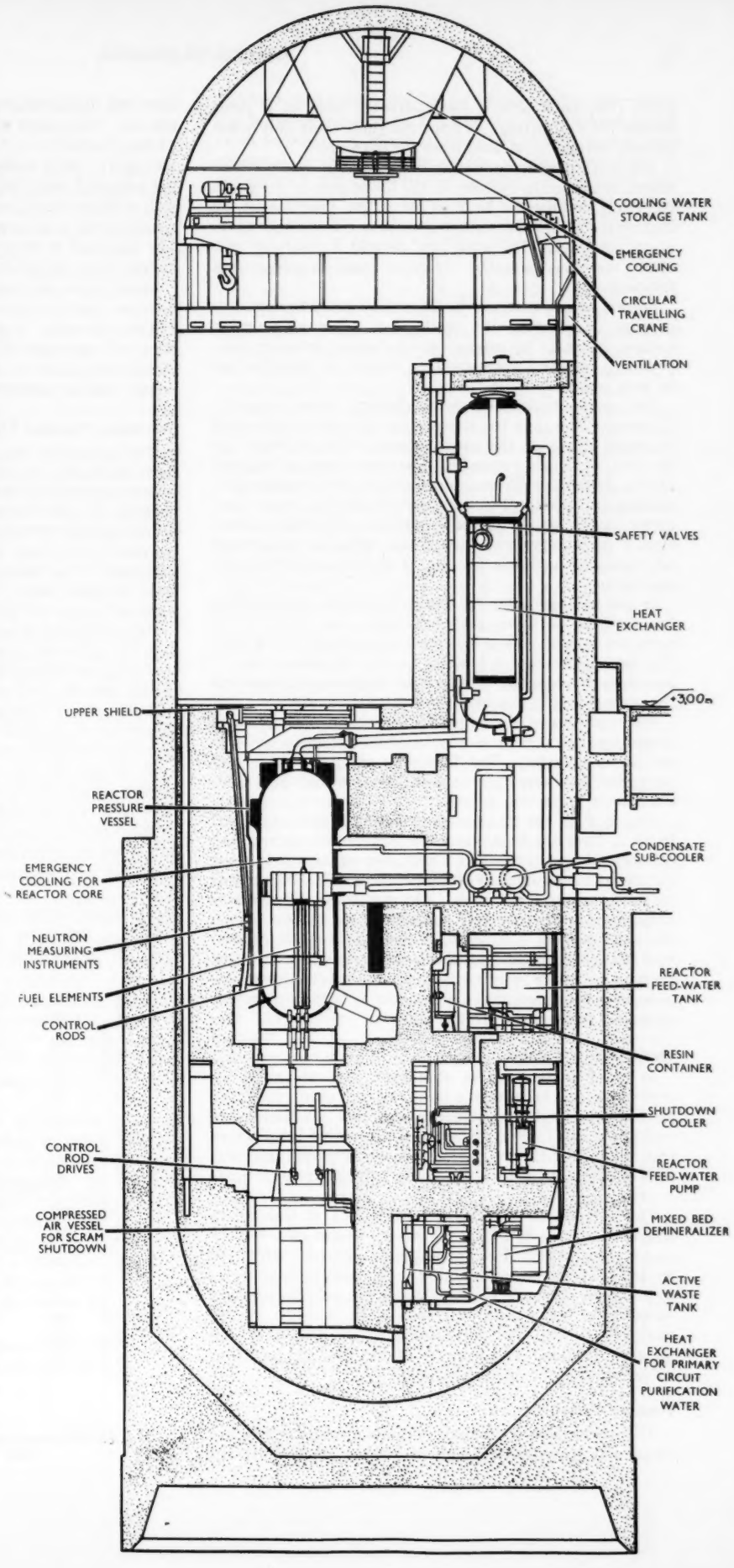


Fig. 5.—Cross section through the reactor building.

gear. The latch arm is inoperative so long as it bears against the nut carriage; it grips the guide shaft only when the nut carriage is released from the latch arm.

The latch arm is connected to the scram piston which moves in the scram cylinder in the lower part of the drive. By letting compressed air into the piston, insertion of the control rod is effected while the air above the piston serves as an air brake. The latch arm permits a reversing only after the mechanically operated nut carriage has followed up.

Besides effecting scram the pneumatic drive has also the purpose of relieving the mechanical screw gear during normal operation by producing a balancing pressure compensating for the force caused by the reactor pressure and its own weight.

The speed obtained by the mechanical drive is approx. 2.5 cm/s. The time for running in the control rod using its whole stroke of 152 cm is approx. 2-3 s of which the first 50% is effected within 1 s. The compressed air required for the pneumatic drives is produced by two compressors, purified in suitable filter units and fed to the scram shut-down installation. There it is stored in 21 vessels so that even if the compressors should fail, sufficient compressed air would be available for the 21 control rod drives for shut-down.

In normal operation the piston is loaded for relieving the mechanical drive gear selectively for two reactor pressures ranges, with a balancing pressure of 3.5/1.8 atm. The back pressure for braking is also dependent on the reactor pressure and by means of reducing stations and change-over valves maintained at 1.4 or 2.8 atm.

The compressed air required for scram shut-down is passed through two three-way magnetic valves in series to the scram cylinder. The three-way magnetic valves are permanently powered and receive their opening signal from the reactor protection system.

The feed for the gland seals through the pressure vessel is taken from the feed water line before the reactor feed pumps and passed through a reducing valve which keeps the pressure constant, and through filters and is then pumped to the 21 control rod seals. The water leaking upwards from the control rod seals passes into the reactor vessel, the water leaking downwards is piped to the reactor feed water tank. For cleaning the control seals, which might become necessary if they become too contaminated by deposits during operation, a separate system is provided, connected to the active storage tank.

Emergency Poisoning

In order to be able to shut-down the reactor in an emergency, e.g., because of a failure of the control rod drive mechanisms, a poison system is installed. To poison the core about 680 l of a 13% solution of sodium pentaborate ($Na_2B_{10}O_{16}.10H_2O$) are used, which on complete injection and distribution have a reactivity equivalent to at least −14%.

The solution is kept in a vessel which is maintained under a pressure of about 130 atm by means of a battery of nitrogen bottles. Four pressure gas actuated valves are so arranged that operation of two diagonally opposite is sufficient to open the line connecting the reactor pressure vessel with the poison reservoir. The solution is fed relatively slowly into the reactor by expansion of the nitrogen cushion. The opening of the four gas actuated valves can only be effected manually.

Pressure Vessel

The reactor core is mounted within a cylindrical pressure vessel with hemispherical ends of 244 cm i.d. and 552 cm over the cylindrical portion; overall internal height is 823 cm. The vessel was fabricated from a special melt of 19 Mn 5 with 0.4 to 0.6 Mo and a low cobalt content (50-100 ppm). Wall thickness in the barrel is 98 mm and in the spherical ends 101 mm. The vessel is internally clad with niobium stabilized 18-8 stainless steel (No. 4550) with a low cobalt and tantalum content, of 6.5 mm thickness. The top head is secured by 44 studs the thickness of the flanges being approximately 340 mm.

Steam leaves the reactor through a single nozzle 350 mm diameter and condensate returns through a nozzle of 330 mm diameter. Four forced circulation nozzles are also provided approximately 400 mm in diameter. These are included to allow an increase in reactor power, by introducing forced circulation, at a later date.

Secondary Coolant Circuit

The secondary steam generated in the heat exchanger flows through a single cylinder, single flow turbine with a one-row control wheel and 15 equal pressure stages running at 3,000 rev/min. The steam volume is controlled by five groups of nozzle control valves, four of which are provided for a load range of 16 MW with the fifth for overloads. The turbine is a saturated steam set with a total of seven water discharges, four of which serve as bleed-off stages for preheating.

The condensate from the condenser is fed by two pumps, with an output of approx. 130 t/h, through a vacuum and low pressure preheating stage and a thermal de-aerating device, into the feed water tank (65 m^3 capacity), which is maintained at a temperature of 143°C. The condensate then flows to the feed pumps and thence through the high pressure preheater to the condensate sub-cooler.

A by-pass to the condenser is arranged across the turbine which enables the whole of the generated steam to be sent to the condenser via by-pass valves. The cooling of the turbine condenser is effected by water from the River Main, which is purified by a "Taprogge" system.

As the heat exchanger is inserted between the reactor, with its constant steam pressure, and the turbo-generator, the pressure of the secondary steam is dependent on the load, i.e., the steam pressure goes down with increasing load. By connecting and disconnecting the turbine bleed-

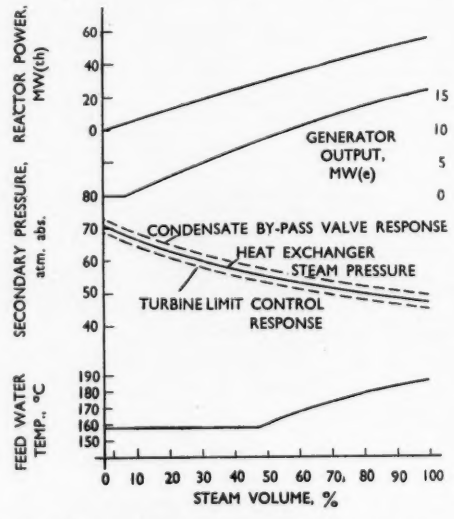


Fig. 6.—Heat exchanger, pressure and feed water temperature curves against power.

off stages the temperature of the feed water can be varied with the load on the secondary side.

Load Following

Operation of the reactor requires on the one hand, in the event of a turbine load drop, to pass the whole steam volume into the condenser and then slowly (in relation to the speed of the reactor control and the admissible temperature gradient in the boilers) to readjust the secondary steam volume; on the other hand to prevent too fast a load take-over for the same reasons in case of a frequency break. This purpose is achieved by the hydraulic turbine control which acts upon the control valves for the nozzle groups as well as upon the condenser by-pass valves. The setting of the condenser by-pass valves should be approx. 2 atm above, and that of the turbine pre-pressure limit control approx. 2 atm below the actual working pressure (Fig. 6).

As the secondary pressure varies according to the load it is necessary to adjust these actual settings to the load. This is achieved by means of a governor, which is operated manually or automatically. If automatically, the range is limited down to 30% load, with a speed of 5 to 15 min variable over the whole load range.

The turbine control installed at Kahl can work not only as a speed regulator but also as a pressure control maintaining the turbine pre-pressure constant.

The turbo set is protected against overspeeding by the governor as well as by the usual rapid shut-down devices. To protect the condenser, the by-pass valves are locked in a closed position if the injected water for cooling the fresh steam and/or the condenser vacuum is not sufficient.

If the turbogenerator comes off when on full load and the condenser is not available as a main heat sink, the reactor shuts down automatically. The decay heat must be dissipated to prevent the safety valves on the primary side in the pressure shell blowing off. The safety valves in the secondary circuit, which have a blow-off pressure of 74 atm and a blow-off power of 62 t/h and are meant only as a protection for the secondary circuit against too high a pressure, would in any case respond too late. For this reason two pairs of valves are provided in the secondary circuit, two pneumatically actuated valves and two safety valves, which limit the primary pressure by making a corresponding reduction in the secondary pressure thus leading to an increase in the temperature difference through the heat exchanger. The pneumatically actuated valves are controlled by the primary pressure and open at approx. 74 atm. The following safety valves prevent a pressure reduction in the secondary circuit to below 42 atm. The blow-off capacity of both pairs of valves is 12 t/h (Fig. 9).

The primary circuit is protected against too high a pressure as mentioned above and by three safety valves which are placed directly on the heat exchanger set to open at a pressure of 87 atm. The reactor output power would increase to nearly double if a failure of the control rod drives occurred and the pressure in the primary circuit then increased up to the blow-off pressure. Therefore, the blow-off capacity of the primary safety valves is arranged to be 230 t/h.

In order to safeguard the flow of water into the heat exchanger, there is provided besides the two full-load feed pumps (having an output at the corresponding full-load pressure of 160 t/h) and the low-load pumps (with an output of 26 t/h at the corresponding quarter-load pressure), a petrol engine driven piston pump with an output of 3 t/h which is able to carry off the decay heat of the reactor core. Likewise, a separate feed leading directly into the heat exchanger ensures the supply of coolant water in case of a fault in the main feed pipe.

Emergency Cooling

In the event of a maximum credible accident, i.e. a rupture in the primary circuit, there is a special cooling installation in the reactor pressure vessel for preventing melting of the core and an emergency cooling system in the building for the rapid reduction of the containment vessel pressure resulting from the flashing to steam of the primary water. The nozzle spray system mounted above the reactor core is selectively fed by the low-load pump in case of high reactor pressure or by both emergency coolant pumps in case of low reactor pressure (Fig. 9).

Initially, cooling of the reactor building is derived from the emergency coolant tank mounted in the containment shell connected to two spray systems with sprinkler nozzles opening at elevated temperature. The emergency coolant pumps installed in the process building are actuated by a signal indicating low reactor water level and high pressure in the reactor building; they feed cooling water to the spray grid above the reactor core as well as two further spray rings in the dome of the reactor building.

In the case of the maximum credible accident, flooding of the whole reactor building is considered. The water required for flooding is drawn from Lake Gustav and is also mixed with sodium pentaborate to prevent the reactor core becoming critical again. For cooling the water inside the reactor building, separate cooling spirals are provided and also intermediate coolers fed from the emergency coolant pumps.

All the effluents from the interior of the reactor building are collected in the reactor building sump and, as in the case of the active collecting tank, passed to the processing plant for purifying if they are contaminated.

All cooling points in the reactor building are connected to the intermediate coolant circuit. The intermediate coolers themselves with the required pumps and filter are located in the processing building; each cooler and each pump is designed for the circulation of a total quantity of approx. 90 t/h. A vessel for maintaining the pressure in the intermediate coolant circuit serves the emergency coolant tank in the reactor building dome. The intermediate coolers and also further cooling points in the

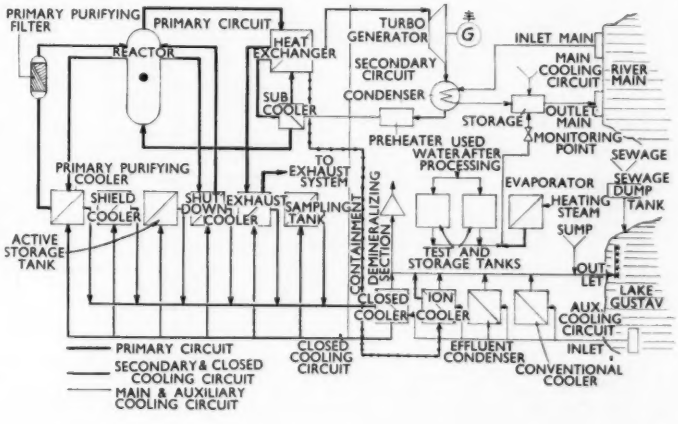


Fig. 7.—Diagram showing main features of cooling circuits.

processing building and in the turbine house receive their cooling water from Lake Gustav in the vicinity.

Shield Cooling

Because of the heat radiation of the reactor pressure vessel and the irradiation of the concrete by neutrons and gamma rays, a vertical cooling spiral is arranged over the whole height in the biological shield and two horizontal cooling spirals are provided at the height of the core. A calculation of the distribution of the temperature has shown that at the height of the core the most favourable spacing of the cooling tubes, from the inner edge of the biological shield to centre line of the tubes, for the vertical cooling spiral in front is about 6 cm and for the horizontal cooling spirals in the middle about 45 cm.

The guide tubes for the ionization chambers inserted in the biological shield are also cooled and contribute to the lowering of the temperature of the concrete. The guide tubes for the ionization chamber as well as the shield coolers are connected to the intermediate coolant circuit. No activation of the circulating water is expected.

Water Treatment

In order to keep the activity in the primary circuit caused by activated corrosion products low, a quantity of primary water is continuously passed through the primary purifying plant. The water is drawn off at the lowest point of the reactor pressure vessel between the control rod glands into the primary purifying cooler, which is designed for a maximum throughput of 9 t/h, where its temperature is reduced from 286°C to 50°C; its pressure is lowered from 70 atm to about 3.5 atm and the water is then passed to the mixed-bed filters. Only one filter operates while the second acts as standby. Before the filters there is a temperature monitoring installation which prevents the admission of water at too high a temperature.

The water, purified by the filters with a pH value of approximately 7 and a conductivity of 0.1 to 0.2 μS, passes to the reactor feed water vessel (20 m^3 volume, 10 m^3 water content), from which it is fed back to the reactor pressure vessel by the reactor feed pumps.

A by-pass line across both mixed-bed filters includes a valve controlled by the reactor water level which enables excess water volume, caused by steam bubbles developing as a result of rapid load take-over, to be discharged quickly into the reactor feed water tank.

All the water required for the primary circuit is fed from the reactor feed water tank to the primary feed pumps through a valve controlled by the water level in the reactor pressure vessel. The tank for its part is kept filled from the refill containers in the purification building with completely demineralized but not de-aerated water. The de-aeration is carried out in the reactor feed water tank under vacuum by atomizing during the refilling procedure. Furthermore, the reactor feed water is constantly de-aerated by the recirculation of water by the primary feed pumps through an atomizing nozzle device into the reactor feed water tank.

During fuel changing the reactor pressure vessel is opened and the water in the reactor is cooled down to 50°C in order to ensure good conditions for observation and to dissipate the decay heat of the reactor core. This is done by the shut-down cooling arrangement. Approximately 100 t/h reactor water is drawn off by a shut-down pump through the shut-down cooler, re-entering the reactor pressure vessel through one of four ports which are provided for a future possible power increase. The shut-down cooler is cooled with coolant water from the intermediate cooling circuit. In order to permit purification of the reactor water during the fuel changing, there is provided, before the shut-down cooler, a connecting pipe-line to the primary purifying plant. The water purified through the filters re-enters the shut-down coolant circuit through a further pipe-line connecting the filters and the inlet coupling of the shut-down pumps.

The fully demineralized water as required for the whole plant is prepared by a water purifying plant with a throughput of 6 t/h. The natural water coming from Lake Gustav flows through two gravel filters and a cation filter into a CO_2 scrubber. Intermediate pumps then pass the water on through an anion filter, a second cation filter, a second anion filter, and two mixed bed filters into the 30 m^3 storage tank, which is maintained at a temperature of 104°C.

Gas Removal

The gases produced by radiolysis and possible fuel damage are continuously drawn off the heat exchanger. The bleed points on the heat exchanger are arranged at the coldest parts and at the corners behind the various baffles where the flow is small. It is expected that under full load about 0.15 kg/h oxygen is formed. The production of radioactive gases including the release of gaseous fission products is very small —of the order of a few cm^3 a day. In order to keep the concentration of oxygen-hydrogen gas in the gas-steam mixture below the explosion limit (4 vol.%), about 100 kg/h steam is drawn off the heat exchanger and reduced by a pressure reducing station to 1.5 atm. After reduction the steam-gas mixture flows through a catalytic recombination plant (two are provided) in which the oxygen-hydrogen mixture is recombined to water vapour. The water vapour

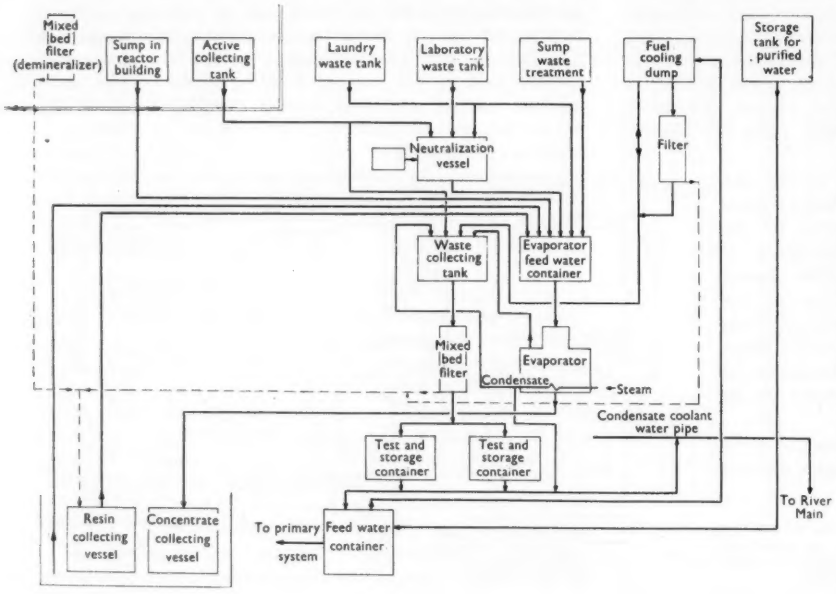


Fig. 8.—Flow sheet of the processing plant.

part is then condensed by means of a gas cooler and the condensate passed to the reactor feed water vessel.

Residual gases flow through the exhaust system to the gas monitoring station in the process building, and thence through vacuum pumps (two, also serving the reactor feed water tank) through a filter and a radiation measuring instrument to the stack.

The gas monitoring station, consisting of two monitoring tanks with circulating pumps and a water jet suction pump, can be put into operation on the detection of fission product gases, and permits their storage at full reactor load for a period of 10 days.

Ventilation

A ventilation plant for the reactor building is installed in the basement of the operations building and consists of a pre-filter, scrubber, two blowers, a heating unit and a fine-filter. The air flow into the reactor building approximates 14,000 m^3/h. The air passes through two quick-closing slide valves having a maximum closing time of 1 s, one of which is operated by compressed air, the other by the dropping of a weight, and is blown into the dome of the reactor hall through an annular pipe-line.

The air then flows into the lower floors according to the principle of guiding the air from the lower activity areas into those of higher activity. The used air passes finally through a collecting channel and two quick-closing slide valves into the processing building, where it is purified a second time through successive fine filters. The two exhaust blowers pass the air into the 39 m stack, of sheet metal (upper edge 50 m above site level), where the air speed on leaving is approx. 16 m/s.

The activity in the stack outlet is composed mainly of the activity of the gases from the de-gassing plant and from the activated air in the annular gap between the reactor pressure vessel and the biological shield. As the argon activity developed in the annular gap is very high, the gap is sealed as thoroughly as possible. It is slightly evacuated by means of a small blower. It is hoped to hold back the gases by this means for a time substantially longer than the half-life of argon so as to keep low the activity of the air leaving the stack.

The processing building and the laboratory rooms are also equipped with an air purifying installation which is designed similar to that of the reactor building. The air volume passed into the processing building is approx. 10,000 m^3/h and to the laboratory rooms approx. 5,000 m^3/h, so that an air discharge volume of approx. 29,000 m^3/h is expected.

Liquid Effluents

All effluents from the reactor building, the laboratory rooms, the laundry, the showers, etc., are passed to the processing plant if they are contaminated. The fluids are subdivided according to their solid content into highly contaminated or little contaminated sections and stored in two different containers in the processing plant, i.e. the evaporator feed vessel (5 m^3) and the effluent collecting tank (20 m^3). An evaporating and condensing plant with a capacity of about 350 kg/h and a stripping factor of approx. 10^5 purifies the highly contaminated effluents and passes the condensate into the collecting tank for the little contaminated effluents. All effluents are then passed from there to a double mixed-bed filter with a throughput of approx. 2.5 m^3/h and thence to the test and storage tanks (each holding 10 m^3), where the purified water is stored and tested. From these two containers the water can either be passed to the refilling tank (20 m^3 capacity) for re-use in the station or into the River Main.

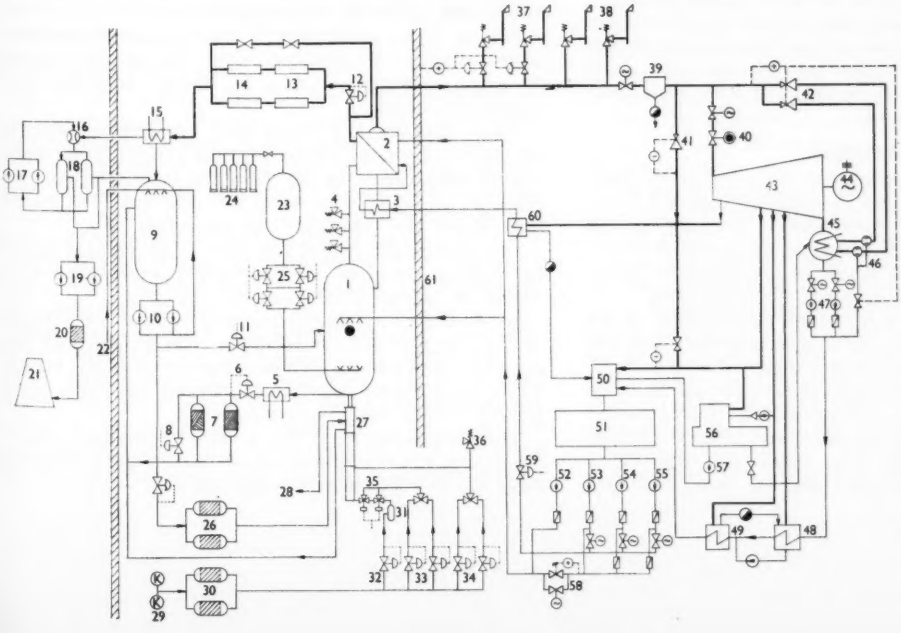
The concentrate coming from the evaporator passes through a pipe in watertight concrete channels to the concentrate collecting tank arranged in the store for active waste. In the same store is also situated the resin collecting tank (10 m^3) in which the resins of the mixed-bed filters are stored coming from the reactor building as well as from the processing plant. It is not intended to regenerate the resins.

A room which can be locked is provided for the non-irradiated fuel elements in the purification plant directly adjacent to the element pond in which 40 fuel elements can be stored in a roundabout.

Fuel Changing

Fuel changing requires the lifting of the cover of the reactor pressure vessel and the raising of the water level

Fig. 9.—Flow diagram for steam supply system.



KEY

1. Reactor; **2.** Steam generator; **3.** Sub-cooler; **4.** Primary safety valves; **5.** By-pass heat exchanger; **6.** Throttling valve in by-pass demineralizer line; **7.** Mixed bed demineralizers; **8.** Blow down valve (actuated by a signal from reactor water level); **9.** Reactor feed water tank; **10.** Reactor feed water pumps; **11.** Reactor feed water control valve (actuated by a signal from reactor water level); **12.** Throttling valve in off-gas line; **13.** Pre-heaters; **14.** Recombiners; **15.** Off-gas cooler; **16.** Water eductor; **17.** Water recirculating pumps; **18.** Gas storage tanks; **19.** Vacuum pumps; **20.** Off-gas filter; **21.** Stack; **22.** Water supply to nuclear steam supply system; **23.** Poison tank; **24.** Nitrogen battery; **25.** Poison valves; **26.** Filters for seal cooling system; **27.** Control rod seal with attached control rod drive; **28.** Blow down line to enclosure drain tank; **29.** Compressors for scram system; **30.** Filters for scram system; **31.** Accumulators (21); **32.** Pressure reducing station for scram pressure; **33.** Pressure reducing stations for balance pressure; **34.** Pressure reducing stations for back pressure; **35.** Solenoid valves (21 × 2); **36.** Blow down valve; **37.** Emergency cooling valves (the pneumatic valves are actuated by a signal from the reactor pressure); **38.** Secondary side safety valves; **39.** Steam dryer; **40.** Turbine trip valve; **41.** Pressure reducing station; **42.** Condenser by-pass valves; **43.** Turbine; **44.** Generator; **45.** Condenser; **46.** Desuperheating unit; **47.** Condensate pumps; **48.** Vacuum preheater; **49.** Low pressure preheater; **50.** De-aerator; **51.** Feed water tank; **52.** Gas motor driven low capacity pump; **53.** Quarter capacity pump; **54.** Full capacity pump; **55.** Full capacity pump; **56.** Storage tank (fed by the demineralizer plant 6t/h capacity); **57.** Storage pump; **58.** Pressure control unit in emergency line; **59.** Feed water control valve (actuated by a signal from steam generator water level); **60.** High pressure preheater; **61.** Reactor containment wall.

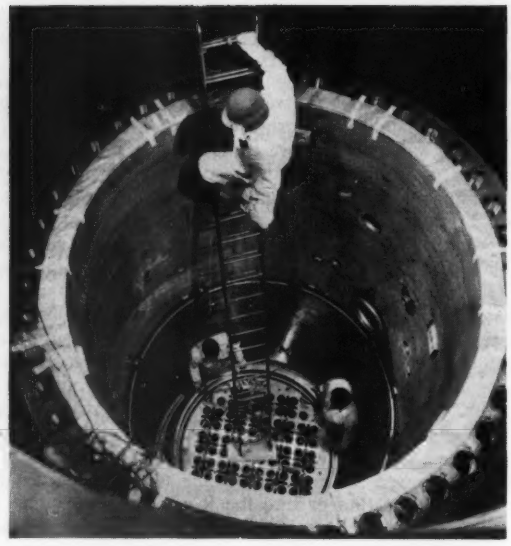


Fig. 10. — Looking down into the core vessel on to the top of the lower core lattice plate.

in the reactor pressure vessel. A flooding container is attached to the flange of the reactor pressure vessel which makes it possible to raise the water level to approx. 5 m above the reactor core for use as a radiation shield. By means of a rotary cover consisting of a concentric steel plate and a second steel plate carried eccentrically by the first plate, of thickness 190 mm, it is possible, using a suitable graduation, to adjust the openings above the fuel element to be changed. An element change flask with a lead wall of 290 mm provided with a winch and a suitable cable is placed on the rotary cover by means of a 30-ton circular crane, mounted in the containment shell. The hook of the fuel flask is fixed by means of long tools, using a second aperture in the eccentric rotary lid, to the handles of the fuel elements; the element can then be drawn into the flask by means of the winch. A carriage running on rails and electrically driven is provided for transporting the flask to the process building through the materials gate. The fuel flask is deposited in the process building, by means of a 50-ton travelling crane, on to a stage in the 7 m deep element pond and the fuel element transferred to its place in the storage grid by a winch, a tilting device and overhead crane. There are a total of 144 places for storing irradiated fuel elements and 18 for storing irradiated control rods. As the fuel elements for the first core are partly equipped with boron steel casings, and the zirconium casings can be used several times, a stripping device is provided in the storage pond. The fully demineralized water in the pond is intermittently purified in a filter installation removing suspended particles.

Turbine Plant and Instrumentation

The generator directly coupled to the turbine is designed for a power of 20 MVA and an ouput voltage of 6.3 kV. It feeds a step-up transformer outside the building, the secondary output of 20 kV being fed by means of underground cables to the switchboard of the Dettingen power station in the vicinity and thence to the public grid.

The two main bus bars for home consumption at the station are at 6 kV and can be coupled together. One bar is fed through a choke from the turbo-generator, the second directly with a separate connection also through a choke from the switchboard at Dettingen. The main coolant water pumps and the two secondary full load feed pumps are connected to these two main station bus bars. They also supply two transformers (one for each bus bar), giving a 200 V output fed to a bus bar distributing to the various buildings. In an emergency, power can be produced by a diesel set having a power output of 640 h.p. which feeds the required current over separate bus bars to the necessary emergency groups.

The emergency lighting, various motor driven valves, instruments and motor generators for reactor protection, etc., are connected to the d.c. circuit which is fed from a battery of 110 cells, with a total potential of 220 V and a capacity of 324 Ah allowing a 3-hour discharge.

For heating the building, for the purification of the effluent and for start-up a steam pipe-line is run from the Dettingen power station to Kahl.

Because of the number of instruments and control devices incorporated in Kahl only some of the more important installations can be selected for discussion and only their basic principles described.

The neutron flux and thus the reactor power output is monitored by means of five ionization chambers and two counter tubes which are mounted outside the reactor in the biological shield. The starting chambers are arranged opposite each other with $\pm 90°$ displacement in relation to the priming source. The two chambers for the transition stage are mounted for reasons of design not exactly diametrically; the three power chambers are equally distributed around the circumference.

For starting the reactor, two boron coated proportional counter tubes are provided up to an output of approx. 10^{-3} of the maximum output, which during power working can be pulled back from the immediate radiation field of the core by separate remote controlled drives. The pre-amplification of the pulses from these two counter tubes takes place in the reactor building whereas the counting rate and period log amplifier is installed in the control room. Each channel has separate counting rate and period indicating meters. A recording device is also available for connecting selectively to the channels.

For the transition range of 10^{-7} to full power, two gamma-compensated ionization chambers are used whose pulses are amplified in the control room by a log N and period amplifier each for the logarithmic indication of the neutron flux and its period. Here also it is possible to switch over selectively to a recorder.

For the output range of 10^{-8} to double the design power output there are provided three gamma-compensated ionization chambers feeding d.c. linear amplifiers with changeable ranges.

Steam pressure and liquid level are watched over by several probes on the reactor pressure vessel. Furthermore, surface temperatures of the vessel and the conductivity and pH-value of the primary water are measured. The same is true for the heat exchanger and sub-cooler.

For each single control rod there is provided a control rod position indicator and also various control devices for testing the correct functioning of the drives.

All auxiliary installations arranged in the nuclear portion of the power station are equipped with the required temperature, pressure and volume measuring devices, most of which are provided with remote controls and indicators or recorders in the main control room.

The purification plant has a separate auxiliary control room from which all important events inside the processing plant can be controlled and observed.

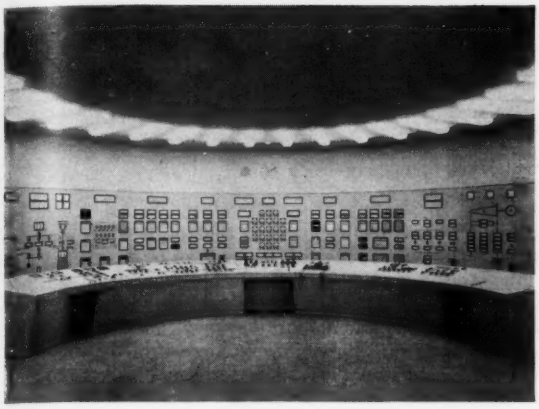


Fig. 11.—Main control room. Left, electrical; centre, reactor; right, boiler controls.

For controlling the activity emitted from the plant there are provided monitoring devices at the outlet of the effluent purification, at the degassing plant and de-aeration from the condenser and also in the coolant water circuit and in the stack which in case of high activity release an alarm in the control room or partly effect switch-off. For monitoring the radiation dose in the reactor building, the processing building, the turbine house and in the main control room is a 10-channel installation which on observing a dose in excess of a predetermined adjustable amount releases an alarm. In addition all dose readings are recorded.

The reactor protection system which selectively, according to the various signals from individual measuring probes, effects either a scramming of the reactor or a controlled insertion of the control rods, protects the station from dangerous operating conditions. Furthermore, signals derived from the reactor protection gear actuate further automatic safety controls such as the automatic starting of the emergency cooling installation. The reactor protection system itself consists of a two-channel system of relays with an additional third channel for monitoring the neutron flux. Three motor generator sets fed from the station battery or from the rectifiers provide a guaranteed source of a.c. for the three safety channels. The relays of each channel are constantly under current and in case of a break of either one or two contacts, dependent on the arrangement of the circuits (two out of four, one out of two, or the like), shut-down procedure is initiated.

Report on the Construction

The ground work, caisson building, soil compression, etc., was started in the middle of June 1958. The caisson for the reactor building was finished in the middle of October and lowered, and the construction of the containment shell started in January 1959 was finished in the middle of March 1959. The pressure test of the containment shell took place during the Easter holidays 1959 at a pressure of 6.8 atm and a temperature of 20°C. The filling in of concrete between it and the caisson was carried out simultaneously with the interior work on the shell and was finished towards the end of October 1959 when the reactor building was ready for the installation of machinery.

The erection work on the operations building and the turbine house was carried out at the same time and was finished at the beginning of September 1959. Over the same period the main coolant water pipes were completed and also the fuel element cooling pond and the coolant

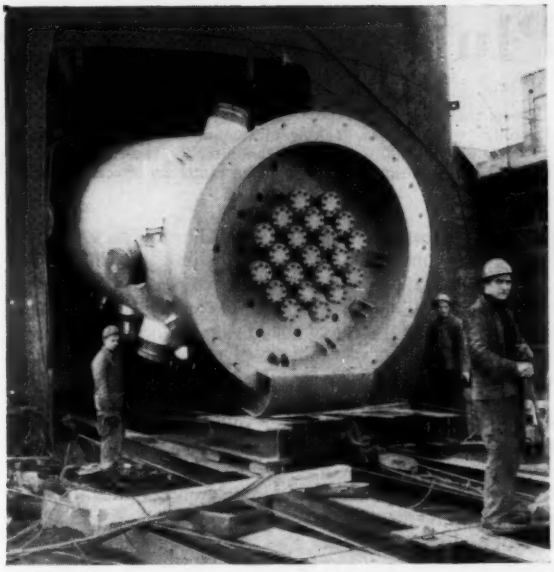


Fig. 12.—Moving the reactor vessel into the containment building.

water outlet building. The foundation on piles for the processing plant was started at the beginning of June 1959, the raw structure of the building finished by the end of November 1959.

The structure of the coolant water pump building was finished by the end of October 1959.

At the beginning of September 1959, the 30-ton circular travelling crane was mounted in the reactor building and subsequently a start was made with mounting the various tanks, pumps and coolers. From December 1959 to February 1960 all further assembly work in the pressure shell was blocked by the construction of the reactor pressure vessel and the heat exchangers. With the condensate subcooler which arrived in the middle of March 1960 on the site, all equipment was installed inside the building, and the assembly of the pipe runs was finished, by and large, by the end of April 1960. All the remaining assembly work including the electrical work for the nuclear steam generating plant occupied the time till August 1960. The assembly of the measuring and control installations took till September 1960.

The assembly work in the turbine house and the operations building started in August 1959 with the installation of the crane. The material for the turbine condenser arrived in September 1959 and this was welded on site. The turbo set and all pipe-lines in the conventional portion were mounted from the beginning of April till the end of September 1960.

The whole assembly of the electric part in the conventional portion took place from September 1959 till the end of July 1960.

After finishing the structural work of the processing building, assembly of the processing plant and the exhaust plant, work on the ventilation plant was started and also on the other circuits. All assembly work inside the processing building was finished in the middle of October 1960.

Preliminary tests of all circuits started in the middle of August 1960 and were finished by the end of October. The subsequent charging of the reactor core and the required zero-power tests saw the core critical on November 13.

At present the plant is ready for the power tests.

Plutonium for Propulsion Reactors

When the civil nuclear power stations in this country come into operation, supplies of plutonium will increase, making plutonium a serious competitor of U^{235}. The use of mixtures of plutonium isotopes can simplify the reactivity control problem in low enrichment propulsion reactors and the reactivity effects of such a fuel are discussed here.

by JOAN HILL
(*Rolls-Royce Ltd.*)

IN a small propulsion reactor which has to run for a long time (say one year) without refuelling, the initial fuel loading must satisfy two conflicting requirements. A large excess reactivity is necessary to overcome the effects of depletion of the fuel and build up of fission products, especially the effects of build up of xenon poison following runs at high power. On the other hand, the limited space available and the engineering complications of a small core often make it difficult to provide sufficient reactivity control by the usual means of pushing in control rods or by removing moderator to increase neutron leakage and resonance capture of neutrons. As the excess reactivity required to compensate for burn up of the fuel is not needed until later in life, the control problem can be eased by using some sort of burnable poison. In this method the core is loaded with a neutron absorber which is converted into less highly absorbing material at about the same rate as the fuel is depleted. Thus the total reactivity swing of the reactor is reduced.

The use of burnable poisons such as B^{10} has been discussed in many papers [1, 2] and the reduction in reactivity swing that can be obtained with a suitable poison is illustrated in Fig. 1. This shows the amount of movable control absorber required at any time to keep the reactor just critical. Cores with a given life require a large amount of control initially if no burnable poison is used, but if a burnable poison, with absorption cross section ϱ times that of U^{235}, is used the maximum amount of control required can be greatly reduced. If the poison and U^{235} cross sections are well matched (i.e., $\varrho \rightarrow 1$) the amount of control absorber required will be reduced to a minimum. An obvious choice of burnable poison for use with plutonium fuel is one of the non-fissile isotopes of plutonium.

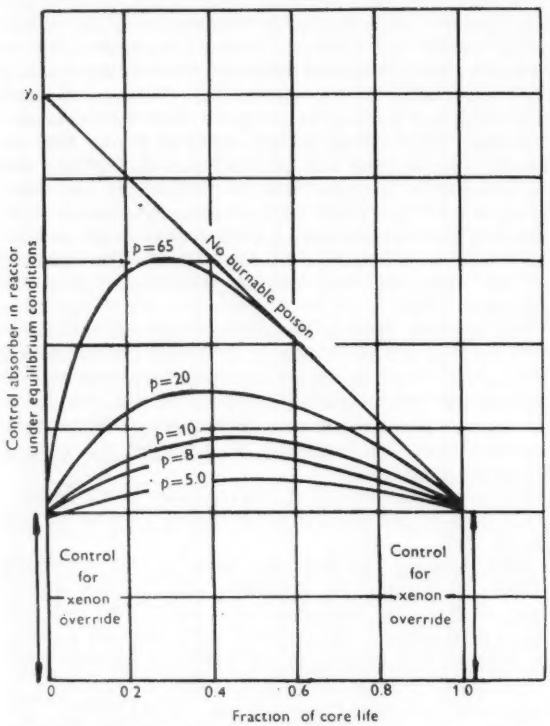


Fig. 1.—Addition of maximum acceptable amount of burnable poison for various values of $p = \frac{\sigma_a \text{ poison}}{\sigma_a - U^{235}}$ for fixed core life[1].

Properties of Plutonium Isotopes

There are three common isotopes of plutonium, Pu^{239}, Pu^{240} and Pu^{241}. Pu^{239} is produced by the neutron capture reaction in U^{238}:

$$U^{238} + n \rightarrow U^{239} - \beta \rightarrow Np^{239} - \beta \rightarrow Pu^{239}$$

while capture of a neutron by one plutonium isotope continues the chain: $Pu^{239} + n \rightarrow Pu^{240}$, $Pu^{240} + n \rightarrow Pu^{241}$.

Of the three isotopes, Pu^{239} and Pu^{241} are fissile by thermal neutrons; Pu^{240} is not fissile but is transformed to Pu^{241} by neutron capture. Pu^{240} satisfies the conditions for a burnable poison, being a neutron absorber which is converted into a material of lower cross section and having the additional advantage of producing Pu^{241} as extra fissile material.

Choice of Fuel Compositions

For reactors originally designed to be fuelled with uranium enriched by a few per cent. U^{235}, the alternative fuel considered is natural uranium enriched with Pu^{239} with Pu^{240} added as a burnable poison. For any given reactor system there will be a limited range of suitable plutonium mixtures. With too much Pu^{239} the initial reactivity will be too high to allow the reactor to be shut down with the control available, while with too much Pu^{240} the reactor will be subcritical at the start of life.

From a survey covering a range of plutonium mixtures it appeared that the most suitable ones were those with Pu^{239}/Pu^{240} ratios of between 3 and 4. As it happens, it is anticipated that the reject fuel from the civil power stations will have Pu contents in this region. The use of these plutonium mixtures is also discussed by Richards [5].

One of the difficulties that can occur with plutonium fuel is the positive moderator temperature coefficient produced by increased capture in the 0.3 eV resonance of the fissile isotope Pu^{239} when the moderator temperature rises. This study was, however, originally carried out for the steam-cooled heavy water reactor [3], which is particularly suited for the use of plutonium fuel as the moderator is insulated from the fuel and the danger from a positive moderator temperature coefficient thereby avoided.

The calculations were done on a very simple model in which the reactor was assumed to be homogeneous, to have a uniform neutron flux throughout the core, and to run at constant power. In practice as the reactivity of this reactor is controlled by removing moderator, there is a central region of the core from which moderator has been drained. In this region (the size of which changes during reactor life), the nuclear constants are rather different from the rest of the core, in particular, the conversion factor is much higher than in the outer annulus. The neutron flux is also distinctly non-uniform, rising to a peak in the outer annulus, but rather more detailed calculations of reactor lifetime show

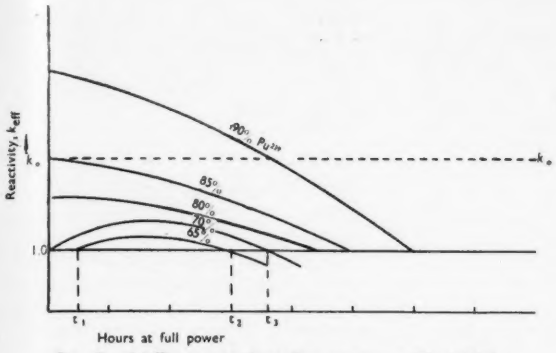


Fig. 2.—k(eff) versus time for reactor with initial enrichment, e'.

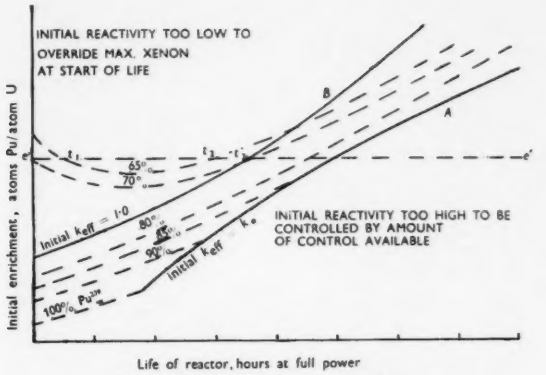


Fig. 3.—Summary of results of Fig. 2.

that the inhomogeneous properties of the core tend to compensate for the non-uniformity of the flux. Thus the approximation of a homogeneous core and uniform flux is reasonable as a first step. The nuclear and reactor parameters are given, respectively, in Tables 1 and 2.

Results of Calculations

In the following discussion, the quantity k(eff) is the effective multiplication constant of the reactor. Fig. 2 illustrates plots of this function against time for various plutonium compositions and a given enrichment (atoms of $Pu^{239}+Pu^{240}$ per atom of U). Where the initial Pu^{239} content is high, k(eff) decreases steadily with time, but where the initial Pu^{239} content is lower k(eff) first increases (as the Pu^{240} is converted to Pu^{241}) and eventually starts decreasing when the effects of depletion of fissile material and build-up of fission products become more significant.

The effect of different enrichments is summarized in Fig. 3, where the initial enrichment is plotted against the reactor life for various plutonium compositions. For high Pu^{239} content the core life increases almost linearly with enrichment, but for high Pu^{240} content certain lines of constant enrichment will cut the curves twice. For example, an enrichment e' cuts the 65% Pu^{239} curve at t_1 and t_2, but it can be seen from Fig. 2 that in this case k(eff) < 1 for $t < t_1$ and $t > t_2$ so before t_1 it is not possible to start up due to the abundance of Pu^{240}. The only points on Fig. 3 which have any practical significance then, are those whose initial k(eff) ≥ 1. Line B is the locus of points whose initial k(eff) = 1.0 and the only reactors of interest are those that lie below B.

A further limiting consideration is the amount of control available to hold down the excess reactivity. This is mainly a problem where there is little Pu^{240} in the fuel and then the reactivity is highest at the start of life. Thus there exists a limiting line A—Initial k(eff) = k_o—which is the locus of all points whose initial reactivities have a value k_o which can be controlled.

The fuel compositions of interest then lie between lines A and B. It is to be noted that there is a range of fuel composition in the region of a Pu^{239}/Pu^{240} ratio of 4 : 1 for which the reactivity lifetime is determined only by the initial enrichment and not by considerations of control.

Fig. 4 illustrates this point in more detail for the steam-cooled reactor described by the parameters of Table 2. It will be seen that the lifetime using pure Pu^{239} is limited to about 3,000 hours (125 days) by the requirement that the control system should be capable of producing a shutdown to −5% reactivity in the most reactive condition. If, however, the fuel contains about 80% Pu^{239}, a lifetime of about 16,000 hours can be obtained, and for a Pu^{239} content of 75% there appears to be no restriction on available life.

The actual enrichment required to give a specified life is rather sensitive to the cross sections used for the various isotopes and to the assumption made in the calculations. One of the major uncertainties in the calculation is the value of the effective cross section of Pu^{240}. This cross section is

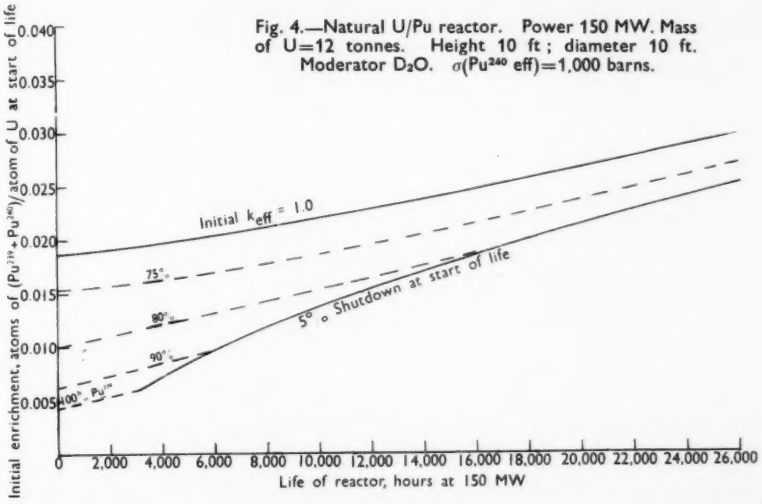
Table 1. Nuclear Parameters

	σ_a, barns	σ_f, barns	ν
U^{235}	566	475	2·47
P_u^{239}	902	649	2·91
P_u^{240}	1,000 (eff.)	—	—
P_u^{241}	1,089	778	3·05

Table 2. Reactor Parameters for SCHWR

Reactor heat output ..	150 MW
Core height	10 ft.
Core diameter	10 ft.
Moderator	D_2O
Coolant	Steam
Wt. of fuel (metal)	12.0 t

Fig. 4.—Natural U/Pu reactor. Power 150 MW. Mass of U=12 tonnes. Height 10 ft; diameter 10 ft. Moderator D_2O. $\sigma(Pu^{240}$ eff)=1,000 barns.



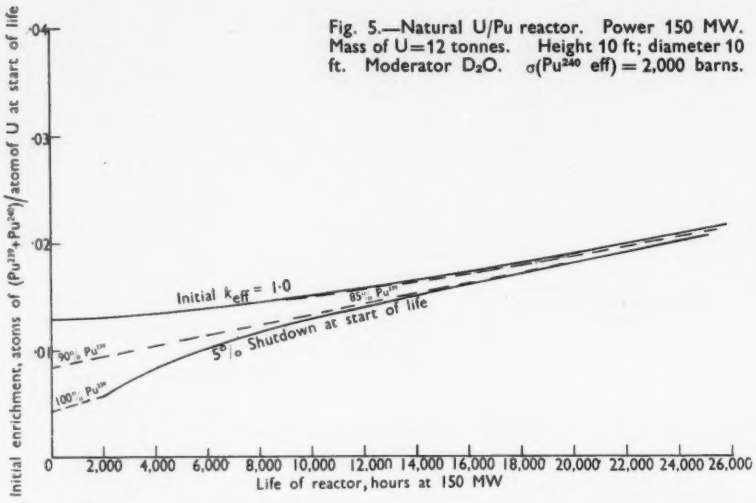

Initial enrichment, atoms of (Pu239+Pu240)/atom of U at start of life
·04
·03
·02
·01
0
Initial keff = 1·0
85% Pu239
90% Pu239
100% Pu239
5% Shutdown at start of life
2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000 20,000 22,000 24,000 26,000
Life of reactor, hours at 150 MW

Fig. 5.—Natural U/Pu reactor. Power 150 MW. Mass of U=12 tonnes. Height 10 ft; diameter 10 ft. Moderator D_2O. $\sigma(Pu^{240}\ eff) = 2{,}000$ barns.

almost entirely due to a very large resonance at 1.0 eV so the cross section is extremely sensitive to the neutron spectrum and to the amount of self-shielding that would occur. A value of 1,000 barns (4) was chosen for $\sigma(Pu^{240}\ eff)$ and calculations were repeated using $\sigma(Pu^{240}\ eff) = 2{,}000$ barns (Fig. 5). A comparison of Figs. 4 and 5 shows that although the absolute values of reactivity life are different, the general shapes of the graphs have not changed and it should still be possible to obtain very long reactivity lives. After short irradiations, however, before much of the Pu^{240} has been converted to Pu^{241}, the reactivity is reduced by the larger cross section. Thus if the Pu^{240} cross section were underestimated it might be necessary to accept lack of maximum xenon override for a short time, but the actual length of life with full xenon override would not be greatly in error.

Conclusions

Although the enrichment (atoms of $Pu^{239}+Pu^{240}$/atom of U) required for a specific reactor to have a given life depends on the reactor structure and the neutron spectrum, the general shape of the curves is not very sensitive to the parameters used in the calculations. Plutonium containing about 80% Pu^{239}, 20% Pu^{240} can be used to give a long core life with minimum control requirements, the conversion of Pu^{240} to Pu^{241} making it an excellent burnable poison.

As plutonium from the civil power stations contains the isotopes in about the correct proportions it can be used to enrich natural uranium for low enrichment propulsion reactors. Such a fuel can be produced without an expensive diffusion plant and it has the added advantage that the burnable poison is already present and is chemically identical to the fuel.

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3. "Steam Cooling." *Nuclear Engineering*, 4, 39, June, 1959, p. 246.
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Pu Test Reactor Starts Up

AN important stage in the U.S.AEC's plutonium research and development programme has been reached with the start up of their Plutonium Recycle Test Reactor (PRTR) at Hanford, Washington. A heavy water vertical pressurized tube reactor, it is to be used for investigating the feasibility of various plutonium recycle concepts. Specifically it provides facilities for:—

1. Irradiation testing of Pu-bearing fuel elements;
2. Direct investigations of reactivity and exposure effects from isotope build up on the U-Pu fuel cycle;
3. Production of irradiated fuels for reprocessing and refabrication studies;
4. Investigation of reactor operating problems for Pu-recycle operations; and
5. Demonstration of the economics and practicability of various fuel cycles.

Currently the reactor is undergoing test operations following criticality. Design output is 70 MW(th). Construction of the $15 million plant started early in 1958. Contractors were General Electric, who will also operate it.

Initial fuel loading of the PRTR contains two different types of fuel element. The Mark I element consists of a 19-rod cluster assembly employing either a plutonium-aluminium alloy or sintered UO_2 pellets. Cladding is Zr-2 and 12 of the 19 rods are wrapped with a 0.072-in Zr-2 wire to maintain alignment of the tubes and provide adequate coolant flow.

The Mark II element is composed of a rod of UO_2 surrounded by two concentric annular rings of UO_2. Zr-2 is again used as cladding. Later elements will contain UO_2-PuO_2 combinations and ceramic mixtures.

There are 85 fuel channels in the reactor, arranged on an 8-in triangular pitch. These, together with 18 shim control rod channels and 13 instrumentation channels, are mounted vertically inside an unpressurized aluminium calandria tank, 84 in i.d. and 115 in in height. The calandria contains heavy water as moderator.

The fuel channels are of double skin construction, the outer wall being of aluminium and an integral part of the calandria. The inner wall is of Zr-2 Heavy water flows upward through the tubes at a pressure of about 1,000 psi as a coolant. Steam is produced in a primary heat exchanger, condensed and then discharged into the Columbia River.

The reactor is surrounded by 71-in thick high density concrete. Adjacent to the reactor are three cells, each surrounded by 5 ft concrete for operational and experimental purposes. There is also an air cooled pit for the examination of irradiated fuel elements and process tubes. The reactor and cells are housed inside a 120-ft tall dome-shaped steel vessel. Outside of this are a cooling pond, the ion exchange resin installation and control and ancillary buildings.

PRTR Parameters

Power level (nominal)	70 MW(th)
Primary coolant flow	8,400 gal/min D_2O at 478°F
Primary coolant pressure	1,025 psig
Reactor Inlet temp.	478°F
Reactor Outlet temp.	530°F
Max. tube power	1,200 kW
Max. tube flow	123 gal/min
Max. tube outlet temp.	542°F
Av. neutron flux (thermal)	8.3×10^{13} neutrons/cm²/sec radial 7.7×10^{13} neutrons/cm²/sec axial
No. of fuel tubes	85
Diameter of tubes	3.350 in
Wall thickness	0.154 in
Length	17 ft 5 in
Weight	85 lb
D_2O flow area for empty tube	8.3 in²
D_2O flow area with Mk. I element	3.56 in²
D_2O flow area with Mk. II element	2.27 in²
Length of Mk. I elements	8 ft 3 in
Active length	7 ft 4 in
Bare rod dia.	0.504 in
Core weight:	
UO_2	122 lb
Pu-Al	32.8 lb
Length of Mk. II elements	8 ft 7 in
UO_2 length	7 ft 4 in
UO_2 weight	141 lb

Thermal Stress in Concrete

By I. W. HANNAH, B.Sc. Tech., A.M.I.E.E.
(*Nuclear Power Division, Simon-Carves, Ltd.*)

In addition to the experimental work undertaken at Hunterston during the construction of the biological shields, Simon-Carves has been carrying out a programme of research in the laboratory to determine the nature and effect of thermal stresses in concrete. A preliminary report on the laboratory work is given below.

THE dimensions of the structural components of concrete biological shields are largely dictated by shielding considerations. The structural duties involved in self support and the support of adjacent buildings and plant could otherwise be achieved by considerably reduced components. Conversely, the necessity for such large dimensions leads to very low structural stresses throughout the completed shield, although in certain local cases of constructional stresses this generalization is not completely true.

In addition to these load induced stresses, a shield will also be subjected to thermal stresses both during construction and under operating conditions. The form and sequence of these thermal stresses has been discussed in several recent publications [1, 2, 3] and no purpose will be served by a further qualitative description. It is sufficient to note here that the large dimensions of shield components cause thermal stresses to be a relatively more serious problem than is usual in structural design. The possible use of the shield for the coolant gas pressure retention in prestressed concrete pressure vessels lends added importance to the problem.

The magnitude of the thermal stresses is largely proportional to the temperature differential across a particular section considered, although additional stresses are caused by the interaction of structural elements of differing mean temperature, in so redundant a structure. Present nuclear engineering practice limits this temperature differential by cooling the inner face of a shield to an "acceptable temperature," although the total cost of this subsidiary cooling, and possibly of an additional steel thermal shield, is very considerable. The definition of this acceptable temperature is nevertheless not simple, as the behaviour of concrete under moderate temperatures is considerably more complex than that of most other structural materials.

In order to obtain more basic data for shield design, Simon-Carves, Ltd., is undertaking experimental work on the reactor shields at the SSEB's Hunterston Nuclear Station, together with a complementary programme in the laboratory. The results from the constructional measurements at Hunterston have recently been published. The scale of the laboratory work precludes firm conclusions, or any suggestions for new design methods, but results seem to demonstrate that the behaviour of concrete under thermal stress is not in complete accord with current design predictions. Very much more theoretical and experimental work is required before thermal stresses in concrete structures can be calculated to the same degree of accuracy as is normal with load induced stresses.

Experimental Approach

The principal difficulties in using a model of a reactor shield for experimental measurements of thermal stress appear to be:—

(a) The complicated shape of the shield would lead to a high proportion of stress due to structural redundancies and a consequent difficulty in analysing the test results.

(b) The experimental difficulty of generating the same temperature differentials in the model as occur in the full scale structure.

(c) Uncertainties of the scale effects involved.

To avoid the scale induced problems (b) and (c), the field experimental programme at Hunterston was proposed. Such full scale work has two major limitations:—

(d) Construction site conditions are not conducive to good experimental work.

(e) The extent of the shield temperature rise under operating conditions must be predetermined during the design of the shield cooling system. Very correctly, this value is chosen conservatively, and the experimental use of the shield is limited to temperatures below those of principal interest to the development engineer.

To obtain more data on the behaviour of a shield in resisting thermal stress, the acceptance of scale difficulties therefore, becomes unavoidable. In the first instance however, difficulty (a) has been avoided by confining the laboratory work to specimens of simple geometrical shapes regarded as simulating elements of a large structure.

Throughout the experimental work the number of concrete mixes has been severely restricted. Gravel and limestone have been used as the principal aggregates as they make concretes of widely differing coefficients of linear expansion. Mix proportions of dry materials have been standardized throughout but variations of water/cement ratio have been introduced to produce concretes of differing strength. The basic properties of the concretes used are given in Table 1.

TABLE 1. Concrete Proportions and Properties

Specimen	Aggregate	Mix proportions				Lin. Coefft. of expansion, /°F	Density at crushing, lb/ft³	28 day cube strength, lb/in²	Modulus of rupture, lb/in²
		Cement	Sand	Aggregate	Water				
Standard	Gravel ..	1.0	1.62	4.38	Varied	7.6×10^{-6}	—	—	—
Standard	Limestone	1.0	1.60	3.92	Varied	4.5×1^{-6}	—	—	—
Slab Test (Fig. 6) ..	Gravel ..	1.0	1.62	4.38	0.55	—	150.0	5,475	735
Slab Test (Fig. 7) ..	Gravel ..	1.0	1.62	4.38	0.60	—	146.6	3,050	440
Slab Test (Fig. 8) ..	Limestone	1.0	1.60	3.92	0.55	—	152.9	5,625	705
Beam Test (Fig. 10)	Limestone	1.0	1.60	3.92	0.50	—	151.5	7,975	930
Beam Test (Fig. 11)	Gravel ..	1.0	1.62	4.38	0.55	—	150.0	4,900	770
Creep Test (Fig. 12)	Limestone	1.0	1.60	3.92	0.50	—	151.5	7,975	930

Material of a Shield

The first experimental work undertaken was intended to define whether shields in general, and Hunterston's in particular, could be regarded as reinforced concrete or whether insufficient reinforcement was provided to alter the structural behaviour from that of an unreinforced concrete vessel. Taking bending

as the criterion, the object of the experiments was to determine the minimum percentage area of reinforcement that would permit multiple cracking prior to failure in a section of beam subjected to a constant bending movement. To attain multiple cracking the residual strength of the first cracked section, with the reinforcement accounting for the tensile force component across the section, must be greater than the uncracked section strength.

Test Measurements

Tests were made on 36 lightly reinforced beams of 4-ft span and varying depth subjected to four point loading. The relationship between the number of cracks appearing in the constant bending moment section of each beam at ultimate failure and the percentage of reinforcement is shown in Fig 1.

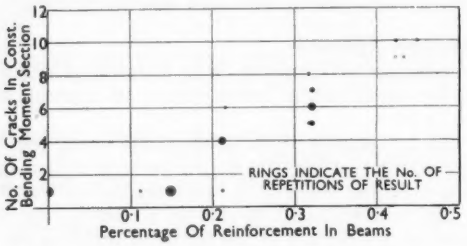

Fig. 1.—Crack distribution in lightly reinforced beams.

Tests with the same objective using cylindrical specimens, of 3 ft o.d. and 6 in wall thickness, in which water heating within the specimen provided the bending moment, proved inconclusive. A temperature gradient of 90 degF through the wall with the water boiling inside failed to crack the specimens at all. These tests were, therefore, discontinued.

From the results of the beam tests it appeared that multiple cracking could not be assured with steel contents much below 0.2-0.3%. As the proportion provided at Hunterston in each face, considered in any particular direction amounted to only about 0.1%, it can be concluded that the shield should be regarded as unreinforced for cracking purposes.

If the biological shield were a simple monolithic structure, subject to a considerable temperature gradient, this conclusion could be significant, in that any cracking induced by temperature would not be distributed but would occur as comparatively large isolated cracks. However, the anticipated temperature gradients at Hunterston are very low indeed and quite insufficient to give rise to this problem. Additionally, the assumption of a simple monolithic structure cannot be sustained because of the numerous redundancies and particularly in view of the inevitable planes of weakness introduced by vertical and horizontal construction joints.

In a structure as inherently stable as a reactor shield, arguments could be readily found for deliberately introducing frequent planes of weakness of this type, even to the extent of using discontinuous reinforcements, to allow predetermined thermal movements to occur without inducing stress.

Effect of Temperature on Flexural Strength

Having established that the percentage of reinforcement used in the shield was insufficient to allow the shield to act as a reinforced structure, the emphasis in later experimental work has been placed on unreinforced concrete.

TABLE 2
Flexural Tests on B.S. Beams at Elevated Temperatures

Beam No.	28 day cube strength at ambient lb/in²	Modulus of rupture of beam lb/in²		Percentage loss of flexural strength of heated beam
		At ambient	At 158°F	
1	5,175	735	—	—
2		690	—	—
3		785	—	—
4	5,175	885	—	—
5		—	640	28
6		—	540	39
7	5,625	785	—	—
8		—	445	43
9		—	445	43
10	5,625	735	—	—
11		—	390	47
12		—	440	40
13	5,100	640	—	—
14		—	345	46
15		—	390	39
16	5,100	685	—	—
17		—	345	50
18		—	*	—
19	5,700	785	—	—
20		—	440	44
21		—	395	50
22	5,700	785	—	—
23		—	440	44
24		—	540	31

N.B.—All beams in this series were 20 in × 4 in × 4 in B.S. 1881: 1952 specimens of standard gravel mix with 0.55 W/C ratio.
* Damaged before test.

The flexural tensile strength of the section thus assumes great importance.

To obtain an indication of the effect of temperature on the flexural strength of concrete sections, two series of bending tests have been carried out. The first series concerned 24 B.S. flexural specimens, 20 in x 4 in x 4 in, tested under standard loading conditions over 16 in span. The beams were all made of the standard gravel aggregate mix described above, with a water/cement ratio of 0.55. Three beams were cast simultaneously and one beam of each group was tested at ambient temperature as a control specimen. The remaining pair were slowly heated in a water bath to 158°F before being tested. The results of these tests are shown in Table 2. They clearly indicate a substantial loss of flexural strength at the comparatively moderate temperature. However, experimental conditions may have accounted for part of the apparent loss of strength in that some surface cooling was inevitable during testing, which would give rise to unwanted thermal stresses in the beams.

A loss of flexural strength at moderately elevated temperatures is confirmed by recently published data,[5,6] but the quantitative evaluation of the loss for concretes of various mixes remains inadequately reported. As a second series of experiments, 12 beams of larger dimensions, 4 ft 6 in x 4 in x 6 in depth, have been cast and tested under four point loading conditions, again in groups of three, with the results shown in Table 3. With these larger beams it became possible to continue heating the beams throughout the test, thereby eliminating the experimental difficulties referred to above. Three B.S. flexural specimens were cast with each group of the larger beams and tested as in the first series. Checks of the effect of temperature on the respective cube strengths were also included. A similar loss of strength is apparent.

It is not suggested here that firm conclusions are to be drawn from these limited tests on small specimens, but it would seem to be a practical worth-while research project to investigate this problem in some detail. Further tests are in hand at the laboratories of Simon-Carves but very much more work remains.

TABLE 3
Second Series of Beams at Elevated Temperature

Beam No.	Aggregate	28 day cube strength lb/in²			Percentage loss of cube strength	Modulus of rupture of beam lb/in²			Percentage loss of flexural strength of heated beam
		At ambient	At 122°F	At 194°F		At ambient	At 122°F	At 194°F	
1 L	Gravel ..	6,875	5,550	—	19	655	—	—	—
2 L						—	390	—	40
3 L						—	440	—	33
1 S	Gravel ..	6,875	5,550	—	19	705	—	—	—
2 S						—	530	—	25
3 S						—	*	—	—
4 L	Gravel ..	6,440	—	5,190	19	600	—	—	—
5 L						—	—	365	39
6 L						—	—	445	26
4 S	Gravel ..	6,440	—	5,190	19	610	—	—	—
5 S						—	—	410	33
6 S						—	—	410	33
7 L	Limestone	6,250	5,525	—	12	655	—	—	—
8 L						—	525	—	20
9 L						—	525	—	20
7 S	Limestone	6,250	5,525	—	12	825	—	—	—
8 S							635	—	23
9 S							690	—	16
10 L	Limestone	5,160	—	3,300	36	675	—	—	—
11 L						—	—	430	36
12 L						—	—	340	50
10 S	Limestone	5,160	—	3,300	36	600	—	—	—
11 S						—	—	430	28
12 S						—	—	*	—

L refers to beams 4 ft 6 in × 4 in × 6 in deep.
S refers to beams 20 ft × 4 in × 4 in deep.
* Damaged before test.

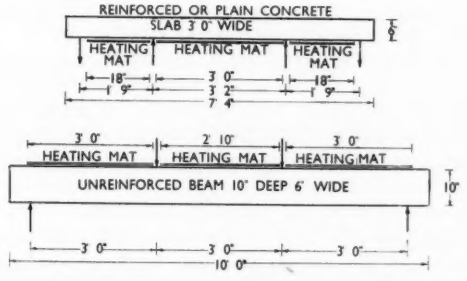

Fig. 2.—Diagrammatic arrangement of beam and slab test rig.

Behaviour Under Short Term Temperature Gradients

The difficulties of measuring thermal strains in concrete models are considerable. Essentially, thermal stress is produced because free thermal expansion is prevented.

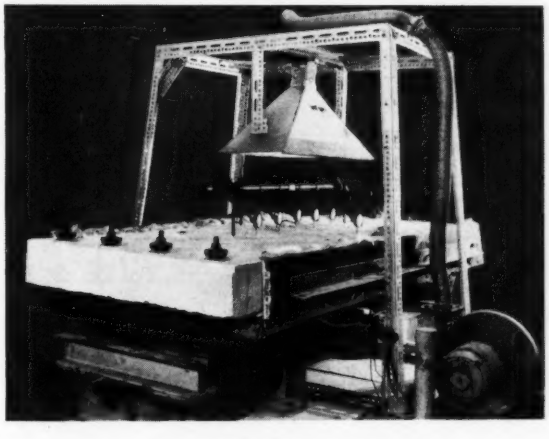

Fig. 3.—Restrained slab test rig.

Thus to measure a thermal strain directly, it is necessary to correct an apparent strain reading by a figure depending on the coefficient of expansion of the material and the temperature at the gauge location. The strain gauge frequently also has a temperature characteristic and with concrete structures further corrections for shrinkage and creep may well be necessary.

As the strain value at tensile cracking of concrete is only likely to be of the order of 10^{-4}, the problem of obtaining adequate accuracy after making these corrections will be appreciated. To simplify the problem experimentally, beams and slabs of concrete have been used to simulate sections of shields. The behaviour of these specimens has also been simplified by sub-dividing the thermal stressing into two independent

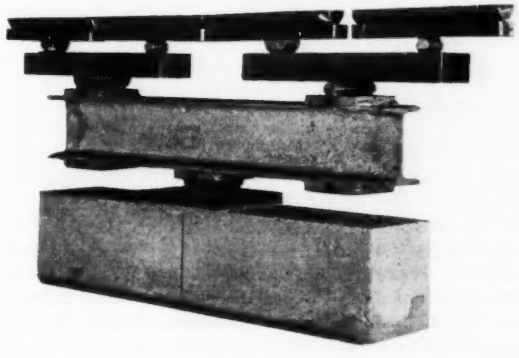

Fig. 4.—Reaction arrangement for slab testing.

operations. The specimen is first supported in such a way that it is free to accept any deformation imposed on it by temperature gradients set up through its thickness. The deformed shape of the specimen is determined for various static temperature gradients.

In the second phase of the experiment, the specimen is mechanically deformed in the opposite sense, and a plot of deformed shape against loading established. The correlation of the temperature gradient and loading causing equal but opposite shape deformation may then be taken to indicate the thermal stress induced in the specimen by the particular temperature gradient, when the specimen is restrained from bending, but free to expand in its own plane. This condition is analogous to that of an element of a simple cylindrical wall subject to a temperature gradient through the wall. It is also the condition most frequently assumed in thermal stress design calculations.

The experimental rig used for the flat slab concrete specimens is shown diagrammatically in Fig. 2 and a view of a specimen under test is shown in Fig. 3. To accommodate transverse deformations of the slab specimens,

the reactions were designed to allow them the greatest possible freedom of movement (Fig. 4). The loading mechanism consisted of a four leg equalizing sling arrangement, seen in Fig. 3, which culminated in a single horizontal beam running longitudinally below the base block of the rig. Load could be evenly applied by jacking between the base block and the beam. Graduated springs were incorporated on the two main vertical tie rods to lend flexibility and loading stability to the arrangement. The heating was achieved with purpose-made glass fabric insulated mats seen in Fig. 5. Thermal insulation was provided

Fig. 5.—Partially erected slab specimen.

below the mats and on the sides of the specimens to reduce lateral losses. To increase the temperature gradients through the slabs a blower was used on the upper surface. In all, 18 slab specimens were tested with this equipment.

Variations in reinforcement percentages between 0 and 3% were tested, with particular emphasis on the values below 0.4%. The cracking behaviour of these specimens incidentally confirmed the limiting percentage of reinforcement determined in the earlier beam tests, 0.2-0.3% again being shown to be the minimum capable of distributing cracking.

Typical results from these tests are shown in Figs. 6, 7 and 8. The deflections represent the mean deflection (computed as a circular deflection pattern and including all the dial gauge readings), at the centre of the 38-in constant bending moment section, relative to the dial stand support at the extremities of that section. Fig. 6 represents the results of testing an unreinforced gravel concrete slab, Fig. 7 a gravel concrete slab with 0.6% longitudinal reinforcement, and Fig. 8 a limestone concrete slab with 0.1% reinforcement. The discrepancies shown between theoretical and experimental values are typical of the results from all the slab tests completed.

The behaviour of the slabs under mechanical loading, shown on the left side of the combined graphs was as anticipated. A reduction of the elastic modulus, E, when the specimen was heated was apparent in all tests, but was more pronounced in the case of limestone concretes.

Under linear thermal gradients, it became apparent early in the tests that truly static conditions could not exist until the slabs were fully dried out. Accordingly readings of deflection were normally taken twice daily, and the heating load changed after each reading. The time interval between successive readings, in hours, is marked on the graphs. Lines joining readings are not intended to represent continuous deformation plots, but merely link the readings in chronological order.

The principal difficulty in quantitatively explaining the appreciable discrepancy lies in the inadequate published data on concrete shrinkage at elevated temperatures. However, it is possible to suggest two principal reasons for the difference.

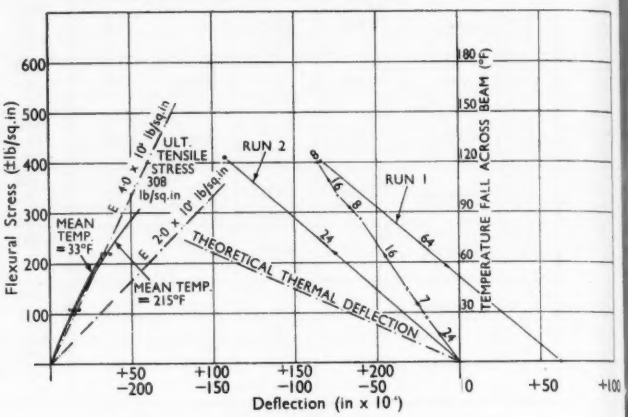

Fig. 6.—Unreinforced gravel concrete slab.

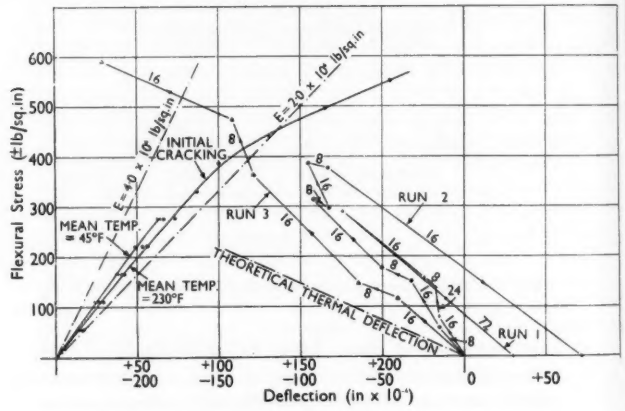

Fig. 7.—Gravel concrete slab with 0.6% reinforcement.

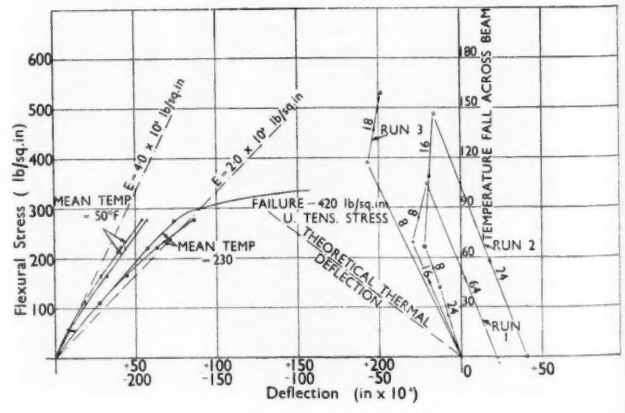

Fig. 8.—Limestone concrete slab with 0.1% reinforcement.

(1) Differential shrinkage caused by the temperature rapidly reducing the expansion deformation below the theoretical value.

(2) The experimental condition at the supports introducing a local heat sink.

Attempts to manipulate the loading rig to eliminate temperature deflections and thus experimentally reproduce the theoretical restraint condition of an element of a cylinder were made. Results confirmed the deflections measured individually during the early stages of the combined test, but shrinkage movements and creep made the later results somewhat confused.

Behaviour Under Linear Temperature Gradients

The limitations of the short term test are apparent. At no stage of the experiment are conditions truly static and the specimen is continuously influenced by both shrinkage and creep in addition to the temperature effect. To isolate these effects the experiment must either be conducted over a longer time scale, which allows full shrinkage to take place, or else the specimen must be surface sealed to limit possible shrinkage. Both methods have disadvantages. Allowing full shrinkage to take place in a small specimen rather invalidates the analogy between the specimen and the massive shield section it represents, as loss of moisture under site conditions must be very slow indeed[8]. On the other hand, effective sealing of concrete surfaces, when the maximum temperature much exceeds 212°F is an experimental problem which has yet to be solved. Even given completely satisfactory sealing, moisture equilibrium within the specimen would introduce corresponding deflections.

A series of 10-ft beams of 6-in width and 10-in depth, made with both limestone and gravel concretes has been cast and tested in pairs. The beams have been supported over a 9-ft span and loaded at the one third points as seen in Figs. 2 and 9. Only one beam of each pair has been subjected to a linear temperature gradient, the other being maintained at ambient temperature as a control. Loading has been identical on both beams of each pair.

At the time of writing, eight pairs of beams have been tested. The precise testing programme of the heated beams of each pair has been unique in order to examine both the procedure and the results more generally, but

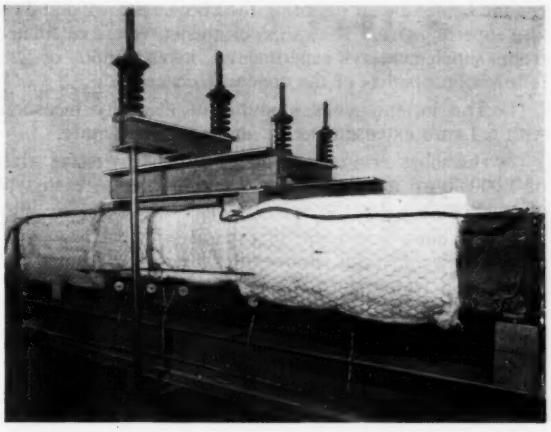

Fig. 9.—Beam test arrangement.

the basic procedure has in all cases been similar to the short term tests, viz:—

(1) The imposition of a linear temperature gradient and recording of the consequent deformation.

(2) The periodic removal and reimposition of the temperature gradient to check the effect of shrinkage.

(3) The application of a force designed to induce a maximum fibre stress of $\pm$ 400 lb/in^2 in the beam, the deflection being in the opposite sense to that caused by the heat.

(4) The continuous plotting of the changing deflection pattern of the central constant B.M. section of the beam.

(5) Again periodic removal and reapplication of load or temperature gradient or both.

(6) After maintaining load and temperature for three months, a final loading of the beam to ultimate.

Typical deflection plots for a beam of limestone concrete and a beam of gravel concrete are seen in Figs. 10 and 11. The deflections are measured relative to a central chord length of 36 in. Curves showing the temperature drop through the beam, the mean temperatures of the beam and the deflection of the control beam are seen superimposed on the heated beam plot. A theoretical deflection plot

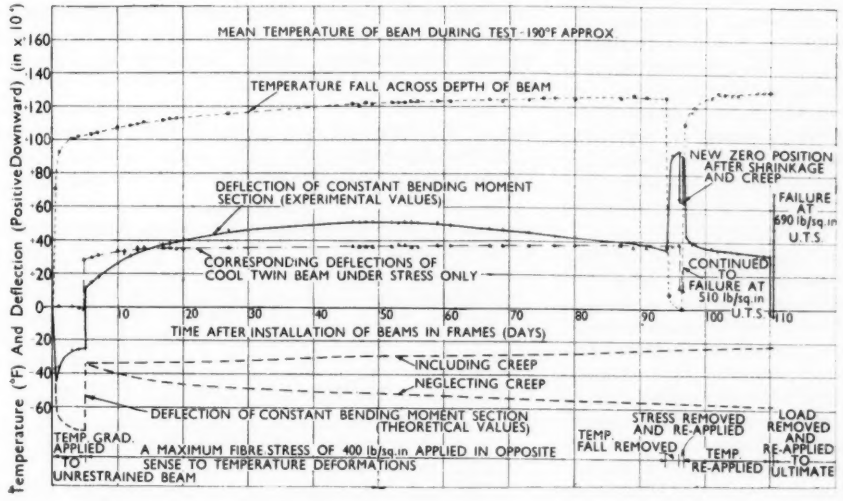

Fig. 10.—Limestone concrete beam: long term deflections.

for the heated beam (ignoring the check stages 2 and 5) is also superimposed. The values on this curve are calculated from supplementary experimental investigation of the following properties of the concretes concerned:

(1) The instantaneous modulus of elasticity measured with a Lamb extensometer at ambient temperature.

(2) The short term creep induced by a compressive stress of 1,000 lb/in² maintained for three months on each type of concrete: see, for example, Fig. 12.

(3) The linear coefficient of expansion of each concrete, measured in apparatus similar to that used by Bonnell and Harper[9], at temperatures up to 150°F.

The comparison of the theoretical and actual deflection values for the heated beam again show most marked

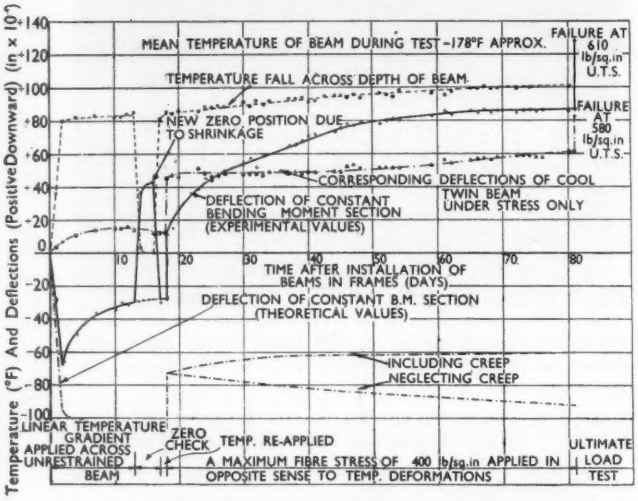
MEAN TEMPERATURE OF BEAM DURING TEST -178°F APPROX.
FAILURE AT 610 lb/sq.in U.T.S.
TEMPERATURE FALL ACROSS DEPTH OF BEAM
NEW ZERO POSITION DUE TO SHRINKAGE
FAILURE AT 580 lb/sq.in U.T.S.
CORRESPONDING DEFLECTIONS OF COOL TWIN BEAM UNDER STRESS ONLY
DEFLECTION OF CONSTANT BENDING MOMENT SECTION (EXPERIMENTAL VALUES)
TIME AFTER INSTALLATION OF BEAMS IN FRAMES (DAYS)
DEFLECTION OF CONSTANT B.M. SECTION (THEORETICAL VALUES)
INCLUDING CREEP
NEGLECTING CREEP
LINEAR TEMPERATURE GRADIENT APPLIED ACROSS UNRESTRAINED BEAM
ZERO CHECK
TEMP. RE-APPLIED
A MAXIMUM FIBRE STRESS OF 400 lb/sq.in APPLIED IN OPPOSITE SENSE TO TEMP. DEFORMATIONS
ULTIMATE LOAD TEST
Temperature (°F) And Deflections (Positive Downward) (in. x 10⁻³)

Fig. 11.—Gravel concrete beam: long term deflection.

differences. Investigation of these discrepancies is not easy and their full explanation entails a very considerable amount of further experimental work. However, several contributory factors are apparent.

Most important of all, shrinkage has been ignored. Fig. 12 shows the shrinkage characteristic of the limestone concrete when stored at 70°F (in the same constant temperature laboratory as the beams, as control throughout short term creep determinations. Curing conditions were the same for all three types of specimen.) Shrinkage is directly related to specimen dimension and is a function of time and temperature. As any apparent moisture movement of the beam must be due to differential shrinkage across the depth of the beam caused by the temperature conditions, it becomes most difficult to correct the theoretical deflection curve for shrinkage with any conviction. Much experimental work on the shrinkage behaviour of concrete specimens of varying sizes under differing temperature conditions remains to be done.

The instantaneous modulus of elasticity is used in the theoretical calculation of deflections. This value is determined on compression specimens at ambient temperature. Deflections taken during the flexural tests described above suggested that this value may be substantially higher than the apparent value in flexure under even these modest temperature conditions. Similarly, the creep value determined at ambient temperature may be considerably lower than the value in flexure at elevated temperature. This is confirmed by recent research work at King's College, London, by Professor A. D. Ross.

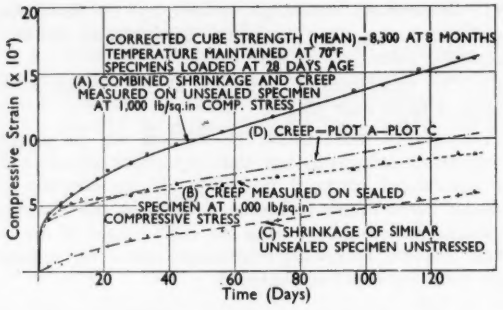
CORRECTED CUBE STRENGTH (MEAN) = 8,300 AT 8 MONTHS
TEMPERATURE MAINTAINED AT 70°F
SPECIMENS LOADED AT 28 DAYS AGE
(A) COMBINED SHRINKAGE AND CREEP MEASURED ON UNSEALED SPECIMEN AT 1,000 lb/sq.in COMP. STRESS
(D) CREEP—PLOT A—PLOT C
(B) CREEP MEASURED ON SEALED SPECIMEN AT 1,000 lb/sq.in COMPRESSIVE STRESS
(C) SHRINKAGE OF SIMILAR UNSEALED SPECIMEN UNSTRESSED
Compressive Strain (x 10⁻⁶)
Time (Days)

Fig. 12.—Creep and shrinkage of limestone concrete.

Imperfections in the experimental technique tend to emphasize the discrepancy between theory and experiment. The use of beams rather than slabs emphasizes the lateral heat loss and thereby introduces non-linear temperature components. Also, the loading points cannot be insulated to the same standard of efficiency as the centre portion of the beam and thus act as local heat sinks. The mean temperature drop across the beams was therefore somewhat lower than the figures indicated on the curves.

Conclusions

It is regretted that conclusions drawn at this stage must be somewhat negative and unhelpful to the designer. Outstandingly, much more basic experimental work on the behaviour of concrete at elevated temperature is required before it will become possible to predict thermal behaviour of structures with the same assurance that is justified for other types of loading.

Considerable care must be exercised in the analysis of thermal stress experiments on concrete models or complicated structural forms if any worth-while results are to be derived. The scale relationships particularly require experimental verification.

Designers concerned with thermal problems, particularly ones involving fairly slender structural members, should appreciate that the stress values calculated by currently accepted methods must be regarded with caution.

To conclude on a more optimistic note, it would seem that the ultimate load characteristics in bending, of sections reinforced with more than 0.3% steel, are largely unaffected by thermal stress caused by moderate linear temperature gradients. The cracking condition largely relieves the thermal stress by reducing the restraint to thermal deformation. Again, however, more data are required to confirm this finding.

Acknowledgment is made to the General Electric Co., Ltd., of England and Simon-Carves, Ltd., for permission to publish this article.

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LOW-FREQUENCY GENERATORS

for Control Rod Operation

OPINION on the question of control rod drives appears to favour the use of a low-frequency synchronous motor with permanent magnet rotor. The use of conventional motors would necessitate the use either of undesirable magnetic clutches within the standpipes or high-ratio reduction gear trains, thus introducing a considerable amount of inertia when it was desired to drop the rods by interrupting the supply and this, in turn, would result in scram times outside acceptable limits. A low-frequency motor need have only sufficient gearing to arrange the drive conveniently, and will provide a fast scram on interruption of supply. It can also be arranged to "hold" the rod in position without any form of brake or mechanical stop.

On the other hand, although the low-frequency motor simplifies the design problems of the actual control rod mechanism, it is essential to provide a low-frequency supply capable of being varied (if two-speed or continuously variable speed is required) or of being "frozen," when the motor is required to hold. A three-phase supply at zero frequency consists, of course, of three d.c. components of magnitude and direction corresponding

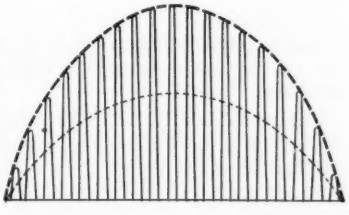


Fig. 1.—Generation of a low-frequency half-wave "envelope" by amplitude modulation of a higher frequency. (Lower curve represents mean current as "seen" by control rod motor)

to the instantaneous values of the phase voltages at the particular point of the cycle at which it is desired to "freeze" the supply. For that matter, it is probably simpler to consider any 3-ph. supply as three d.c. voltages varying sinusoidally with time.

Low-frequency Supplies

One other important requirement of l.f. supplies for control rod operation is purity of waveform of the output. Even slight "kinks" or steps in the waveform, particularly at the zero position, can cause "cogging" (i.e., jerky rotation at a fraction of true synchronous speed) of the motor.

There are a number of schemes for l.f. generation, most of which involve comparatively large rotating machines. A scheme which is essentially static has been developed by Bruce Peebles and Co., Ltd., of Edinburgh, who recently gave facilities for inspecting some of the equipment. As has been previously announced, this company has been awarded a contract by Atomic Power Constructions, Ltd., for completely equipping the Trawsfynydd power station with low-frequency generators for the control rod drives.

Operating Principles

Although the Bruce Peebles scheme is not entirely static, it is almost completely so, the only rotating machines being motor-driven magslip transmitters and, in certain cases, cam-operated contactors. Otherwise, practically the entire equipment is of the "black box" type.

Fig. 1 shows in simplified form the method by which amplitude modulation of a supply frequency can be made to produce an "envelope" of sinusoidal form at low frequency. This amplitude modulation is obtained by means of a magslip transmitter, motor-driven at a speed corresponding to the frequency required. This small output is used to modulate the control bias on a magnetic amplifier which feeds the control rod motor. A block schematic is shown in Fig. 2, which shows a unit arranged

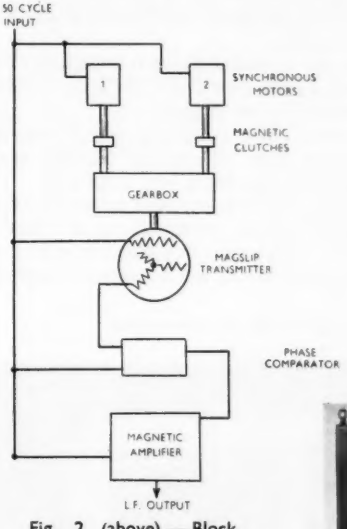


Fig. 2 (above).—Block diagram of a typical generator unit.

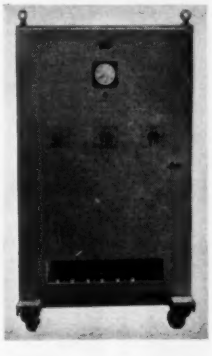


Fig. 3 (right).—External view of a typical cubicle.

for dual-frequency output (in this particular case 0.25 and 0.775 c/s). The magslip is, in this case, driven through a gearbox from one of two synchronous motors fitted with magnetic clutches, either of which may be engaged according to whether slow or fast rod withdrawal is required.

Reversal of rotation is by means of a changeover contactor in the motor supply.

Since the output from each phase of the magnetic amplifier provides only a "half-wave" l.f. supply, it is necessary to provide some means of restoring it to its normal full-wave form. Where the current output is not very large, this is arranged by connecting duplicate amplifiers in "push-pull" formation through a resistive-inductive ballast or mixing circuit, in which the difference of the components is fed to the load, and their sum is fed to the ballast. Where large outputs are required, instead of push-puil operation and ballast mixing, mechanical commutation is provided by means of cam-operated contactors driven from the magslip drive.

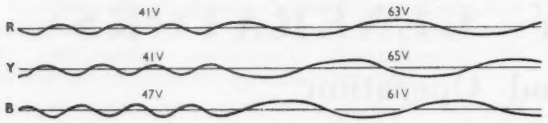


Fig. 4.—Oscillogram of l.f. generator output while supplying the equivalent of 3 control rod motors.

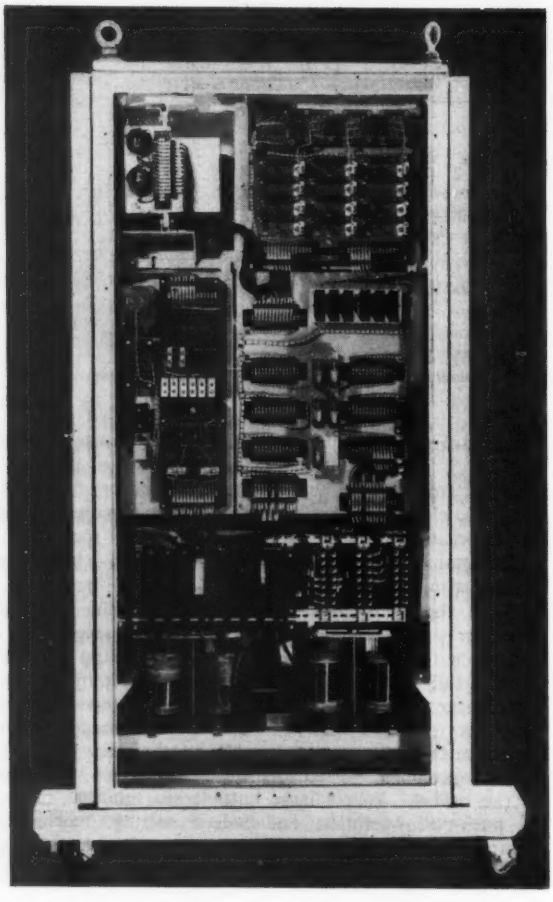
The magslips used are of Muirhead manufacture, driven by Evershed and Vignoles synchronous motors through special gearboxes and Westool magnetic clutches. Rectifiers are of the silicon type, manufactured by International Rectifiers, Ltd.

Amongst the automatic protective features provided is the continuous monitoring of the vector sum of the l.f. power outputs so that, in the event of loss of output on any phase, warning and automatic transfer to a standby equipment can be provided.

Switching facilities are provided on each equipment for transferring command of the unit from the main control room to "local" control at the cubicle.

As is generally realized, there are many control rods on a reactor which, having been adjusted at start-up, may not require to be moved again for a very long time. To make provision for this, they are arranged to be switched over from their appropriate l.f. generator to a "hold" equipment. This does not contain any magslip unit, and makes no arrangement for varying the frequency; it merely provides a d.c. supply at the appropriate voltage, across two of the motor phases, by means of transformers and rectifiers.

Fig. 5.—Internal view of cubicle (side).



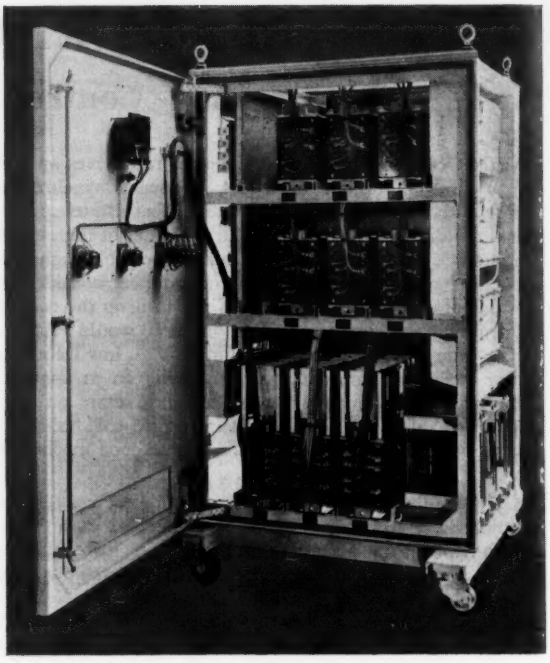


Fig. 6.—Front view of cubicle, with panel open.

That there is little distortion introduced into the output waveform is shown by Fig. 4, which is a copy of an oscillogram of the output from a pilot unit which has now been dispatched to Fairey Engineering, Ltd., for intensive testing with the control rod motors. This will replace an experimental model which has been undergoing investigation for some time, since, although the actual contract has only just been placed, work on this scheme has been in progress for more than two years.

Scope of Scheme

Although previous reference was made to "black boxes" the units are considerably larger than one usually imagines in this connection. Each unit for the control of a particular section of the control rods is built into a steel cubicle; a typical cubicle would be 6 ft high × 4 ft × 3 ft and would weigh in the region of 1 ton, since the magnetic amplifiers are by no means small. In fact, an outstanding advantage which Bruce Peebles possessed was many years of experience in the design and manufacture of small distribution transformers, which was of considerable assistance in the construction of large magnetic amplifiers and inductances.

Future Trends

Although the manufacturers feel that in this equipment they have improved—particularly in purity of waveform—on previous schemes, they do not regard this by any means as the ultimate solution. Developments envisaged for future applications include the complete elimination of rotating parts, possibly by the use of solid-state devices.

We are indebted to the Electronics Division of Bruce Peebles and Co., Ltd., for facilities afforded in preparing this article.

Pneumatic Gauges for In-pile Measurements

By J. PEFHANY
(*Atomic Products Engineer, Orenda Engines, Ltd., Toronto*)

A description is given of the development of a pneumatic gauge for in-pile measurements of very small movements. Work done suggests that accurate results can be expected at temperatures in excess of 400°C.

VARIOUS methods have been attempted for the measurement of small movements inside nuclear reactors. Electrical transducers in various forms have been tested with varying degrees of success but never with more than moderate accuracy. Optical methods are difficult to apply because readings must be taken out through long, small-diameter holes and a considerable temperature gradient (up to 500°C). The readout of optical equipment cannot be positioned at a remote location and therefore obstructs the normal functioning of reactor service machines. Methods using mechanical amplification and

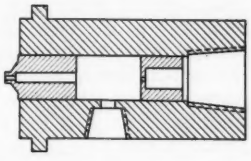


Fig. 1.—Test nozzle for preliminary tests.
(Made from stainless steel and hardened.)

direct transmission or scratch marking techniques are severely limited by the small diameter normally available (particularly into the intense flux regions) and by the difficulty of eliminating errors due to temperature gradients or undesired loading of the measured specimens.

Electrical methods offer many advantages but are limited because no wire insulation is available which has been proven during operation under intense radiation (2×10^{13} (fast) n/cm^2 sec) for the length of time required (up to one year). For these reasons emphasis was placed on a pneumatic approach since all the components of such a sensor (metal and gas) are extremely radiation damage resistant compared with plastics and/or ceramics which must be employed in electrical systems.

Preliminary Results

An investigation into the types of existing pneumatic gauges and their problems and performance indicated that the most applicable gauge design showed 1-2% drift per 8-10 hours of use. The available resolution was adequate

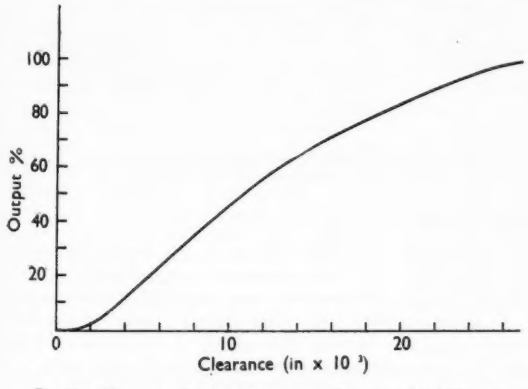


Fig. 2.—Output of original test nozzle over the full range of movement.

but to combine the desired range (0-0.020 in) with high resolution (2-5 μin) was likely to entertain some difficulty.

In co-operation with the Moore Instrument Company, a design was arrived at and supplied by Moore which was expected to display the required range, resolution and improved stability. It was decided to employ, as the gauging fluid, clean dry nitrogen of 0.004% maximum

Fig. 3.—(Right) Assembly (CSK 99) for general nozzle tests.
(Built for operation up to 400°C from hardened stainless steel and titanium carbide.)

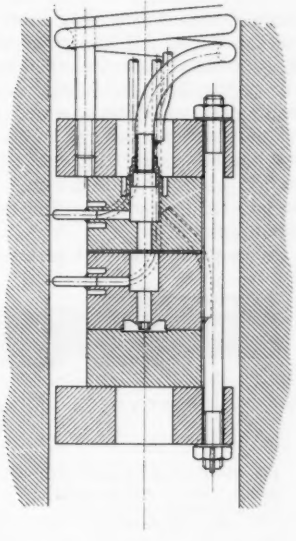
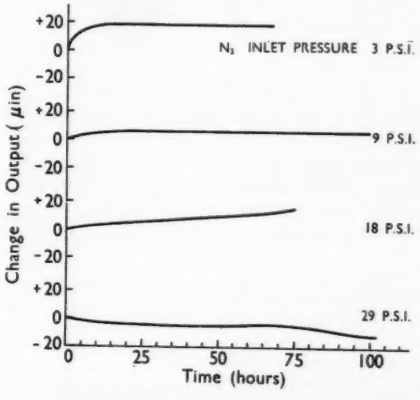


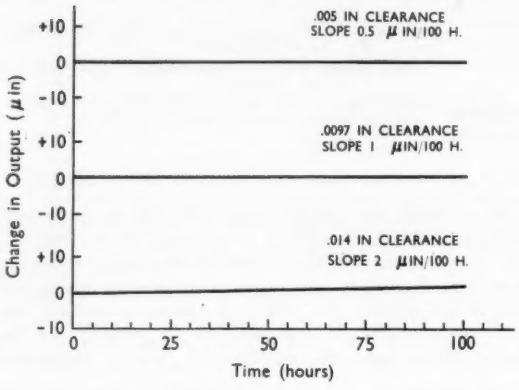
Fig. 4.—(Below) Stability tests at various inlet pressures.
(Note the more pronounced non-linearities and poorer stability above 9 p.s.i.)



impurities, which is available in liquefied form so that only infrequent changing of the supply bottle is necessary, even during continuous measurement. Gas consumption rate can be an important factor in the cost of operating pneumatic gauges, particularly since continuous recording of results over long periods of time is often desirable.

The initial nozzle and restriction is shown in Fig. 1. It was manufactured from 410 stainless steel, hardened and lapped in critical areas. A calibration curve of this nozzle (Fig. 2) showed that a range of 0.020 in was possible with

Fig. 5.—Stability tests at three clearances.
(Drift rate appears slightly higher at increased clearance.)



some change in sensitivity from the " close " baffle position to the " open " baffle position. At the " close " baffle position the sensitivity of 0.004 inHg per μin of baffle movement drops to 0.001 inHg per μin at the " open " baffle position. This was very encouraging and a 25-hour stability test was carried out at room temperature which resulted in a total " drift " of about 50 μin. This amounts to 0.25% of full scale and could, therefore, be considered to be a 25-1 improvement in stability over its commercial counterpart.

Since a minimum test period of 1,000 hours' continuous

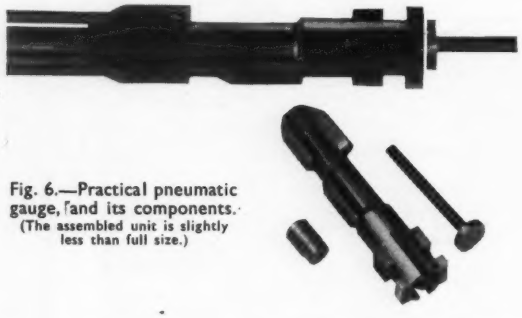


Fig. 6.—Practical pneumatic gauge, and its components.
(The assembled unit is slightly less than full size.)

duty at 400°C was considered desirable, a further improvement of at least 200 times remained to be realized to obtain a stability of $\pm$10-15 μin over the test period. These results, obtained with a minimum of specialized test rig, were sufficiently encouraging to plan a programme that would lead to determination of the various factors causing drift. These would be thoroughly investigated in

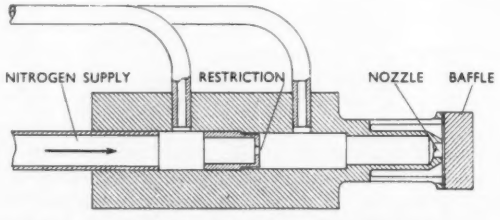


Fig. 7.—Test nozzle (CKS 117) for thermal distortion tests.
(Made from 400 series stainless steel; one-piece nozzle housing and baffle support ring. Baffle brazed in position.)

the important " close " nozzle-to-baffle clearance range and at elevated temperature (400°C). Possible errors due to distortion through thermal ageing of a practical pneumatic gauge design were also to be investigated along with the effects of temperature cycling.

Design Considerations

It has been indicated that a rather hard, wear- and corrosion-resistant material is essential for the flow

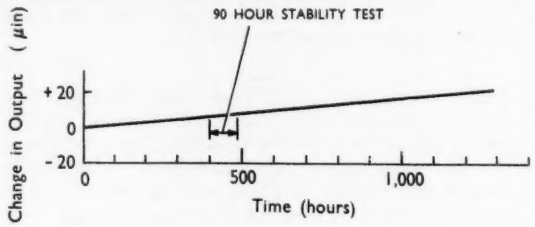


Fig. 8.—Distortion test results for Fig. 7.
(Rate of distortion is constant and very small.)

passages. The superhard materials such as the carbides were considered to offer little advantage under the conditions of these tests as they would introduce the possibility of increased distortion under irradiation. All passage surfaces were carefully finished to a very " flat " and smooth finish, while care was exercised to maintain sharp and regular flow passage discontinuities. The selection of an inert gas of extreme purity minimizes any problems with foreign matter build-up, particularly on the baffle. An optimum operating pressure that would ensure sufficient scrubbing of the baffle surface yet minimize erosion or wear of the nozzle and restriction was desired and the test programme was arranged to determine this pressure. An investigation of linearity was not planned, since the characteristic of Fig. 2 is of the preferred shape in that the sensitivity (resolution) is more or less a constant percentage of the actual reading for various baffle clearances. The possibility of attaining a linearity of the same order as the desired accuracy and stability is most unlikely within the practical limitations of flow rate and sensitivity so that a linearity correction must be accepted.

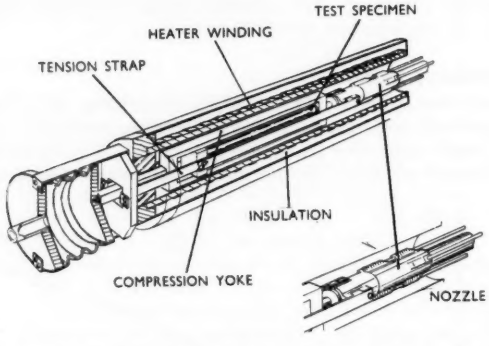


Fig. 9.—In-pile test capsule fitted with nozzle similar to Fig. 6.
(Construction suitable for operation to 500°C.)

Further Testing

To investigate the effect of wear on the nozzle and restriction edges and foreign matter accumulation on the baffle and nozzle surfaces, the test unit CSK 99 shown in Fig. 3 was manufactured. The material chosen was 440 stainless steel and during the testing a titanium carbide restriction was substituted for the 440 restriction with no loss or gain in performance.

Stability tests at inlet pressures of 3-29 p.s.i. at 0.005 in

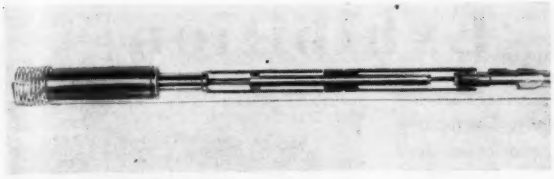


Fig. 10.—View of capsule similar to Fig. 9.

clearance were carried out for 70-120 hours at 400°C. From these results (Fig. 4) it was decided to conduct all further tests at 9 p.s.i. inlet pressure, as this was the highest pressure at which stable results were obtained. Further stability tests of approximately 100 hours' duration at 400°C with 9 p.s.i. inlet pressure at gaps of 0.005 in, 0.0097 in and 0.014 in were carried out. These results are plotted in Fig. 5 and indicate a maximum drift of about 2 μin per 100 hours. The limit of error in the complete system is about 5 μin and the results have been corrected for variations in barometric pressure.

Several times the unit was removed from the furnace and allowed to cool. In addition, the gas inlet pressure was cycled above and below test pressure. There was no measurable effect on output (less than 2 μin) as a result of these disturbances.

While tests were in progress on CSK 99, a test unit similar in size and geometry to a unit to be evaluated in-pile and to one to be employed in the initial in-pile physical test (Fig. 6), was built as CSK 117 (Fig. 7).

By this time it had been decided that continuous indication would be too expensive in gas cost and therefore gauge operation would employ full inlet pressure only while actual readings were being taken, with about one-tenth the pressure being applied at other times, the reduced flow being maintained to inhibit corrosion and wear.

CSK 117 was subjected to a 1,200-hour run (intermittent flow) at 400°C with readings being taken at 9 p.s.i. inlet pressure. After 400 hours this test was interrupted with a 90-hour run at continuous flow at 9 p.s.i. Fig. 8 shows the results of these tests. The total change is approximately 20 μ in, which is nearly all attributable to thermal distortion. A unit similar to CSK 117 is being irradiated to measure the extent of reactor induced distortion. CSK 117 was subjected to thermal cycles between 400°C and room temperature at rates of change comparable with reactor-induced changes. These are in the order of 100°C/min cooling and 30°C/min heating. The maximum change through 14 such cycles was less than 5 μin.

Conclusions

The maximum errors to be expected from a properly designed pneumatic gauge are in the order of 0.1% of full scale per 1,000 hours of operation at 400°C. Most of this small error can be corrected since it is unidirectional and of essentially constant rate with time at temperature. Operation at much higher temperatures is possible with little change in design or materials. Pneumatic gauges may therefore be applied with considerable success to critical in-pile gauging problems since the in-pile performance can be expected to be substantially the same as out-of-pile tests indicate. The ability to make measurements of this precision under such adverse conditions in very restricted space will be of great value in applications such as the creep test capsule of Figs. 9 and 10, which incorporates a pneumatic gauge and will function at elevated temperature in the most intense radiation fields available.

Acknowledgment

This work was undertaken on behalf of Atomic Energy of Canada, Ltd., whose permission to publish these results is gratefully acknowledged.

The IAEA Reports on Finland

IN itself the IAEA report on Finland* is an interesting document. Whether it was necessary to have the sponsorship of the Agency, however, is questionable. It could well have been compiled by the country's own power industry. Indeed, in its conclusions the report goes no further than reiterating what had already been foreseen by the industry†—that there is a real potential for nuclear power in Finland but the earliest date for an economic station is 1970. The report is equally unoriginal in its main recommendation—that before a nuclear power programme is embarked upon the country should make further studies.

For the record these recommended studies are: a study of the domestic and foreign exchange requirements of a nuclear power programme; a detailed comparison of fuel cycle costs including the possibility of using Finnish uranium; optimization studies for determining the reactor sizes and the turbo alternator unit sizes for best operation within the interconnected system; power cost investigations based on different reactor systems; and the possible advantage of non-nuclear superheating. It would surely have been more useful if the IAEA had taken one of these as their starting point instead of leaving Finland no further forward in considering nuclear power than she was before this report.

It might have been even more appropriate if the Agency had perhaps studied the possibilities of using small power reactors for both heat and electricity production (also recommended in the report), an investigation of small reactors for use in remote areas or even a study of nuclear power and the ice-breaker building industry.

In answer to all this the Agency would no doubt point out that the compilation of the report was made at the instigation of the Finnish Government. Further they are confident that though the report is limited to the specific conditions of Finland it will be of use to other countries, particularly those dependent to a large extent on hydro power.

Briefly, the report contains detailed analyses of the contributions of the various power sources—hydro, coal, peat, timber and industrial wastes; an assessment of the power needs during the current decade and how these will be met by conventional power sources, and a projected cost comparison of nuclear and coal fired stations.

Currently, from 70 to 85% of the country's electricity requirements are met by hydro power. Thermal stations are used to supplement this during the winter months when demand is high and water is low. Stations for this purpose are relatively small and have low utilization factors.

During the current decade, it will be impossible for hydro power to keep pace and already half of the hydro power potential of Finland is exploited. Many of the remaining undeveloped sites will require smaller stations or, because of their awkward positions, will involve expensive construction projects. Thus the cost of hydro power will go up. In these conditions thermal stations will come into their own—so much so that by 1970 it is expected that thermal plants with utilization factors of over 75% will be feasible. Whether nuclear power will prove economical by then will depend on trends and developments not only in the nuclear world but also in the conventional field.

* "Prospects of Nuclear Power in Finland," IAEA Technical Report Series No. 2.

† "Finnish Power Position," *Nuclear Engineering*, pp. 205-206, May, 1960.

Institute of Physics
Physical Society

1961 Exhibition

THE PHYSICAL SOCIETY'S annual exhibition of scientific instruments and apparatus is one of the activities which has been taken over by the amalgamated Institute of Physics and Physical Society. This year's show, the 45th in the series, took place as usual at the Royal Horticultural Halls, London, from January 16-20. In character it has not changed and it serves to provide a comprehensive and useful panorama of developments that are going on in the instrument world. In this summary we highlight some of the exhibits of interest to the nuclear engineer.

AEA—R and D, Capenhurst

The free acidity of solutions of uranyl nitrate in nitric acid is a critical parameter in chemical processing of spent fuel elements. In the acidity meter developed by the D and E Group of the R and D Branch, Capenhurst, the acidity of a solution is derived from combined measurements of its density and electrical conductivity. A continuous signal, suitable for automatic control, is thus obtained from simple physical measurements which can be made remotely on acid and highly radioactive liquids. Also shown by the group was the scanning Fabry-Perot spectrometer for determining isotopic abundances.

AEA—Winfrith AEE

The AEE, Winfrith, is developing a magnetic flow-measuring instrument for non-conducting fluids, slurries and dusts. In conventional magnetic flow-measuring instruments the e.m.f. generated when a conducting material flows through a magnetic field is used to measure the flow, the e.m.f. being measured by means of probes in the material. In the Winfrith apparatus the probes are replaced by plates and the e.m.f. is produced by an alternating magnetic field. The instrument will measure the flow of a material having zero conductivity since the capacitor, formed by the plates, always has a finite impedance. The e.m.f. generated is closely related to the mean particle velocity and the short-circuit current produced by this e.m.f. is related to the mass flow through the capacitor.

British Iron and Steel Research Association

The evolute camera unit on show at the BISRA stand is designed to reproduce on a single flat plate an image of the complete surface of a cylindrical specimen. It has, in fact, been used to make permanent records of the conditions of short lengths of cast iron and steel pipes but has other applications.

Also displayed was a prototype exo-electron testing apparatus for studying surface phenomena such as oxidation, mechanical abrasion and metal fatigue.

Cambridge Instrument Company

The prototype multipoint boiler feed water analyser shown was designed to record continuously on one chart the results of up to 12 different analyses. At present only four channels have been developed—for measuring dissolved oxygen, dissolved hydrogen, conductivity and the pH value. Three other channels are in the process of being developed by Cambridge Instrument—for measuring residual hydrazine, silica and carbon dioxide—and it is expected that uses for the remaining eight channels will eventually be found. A useful feature of these multi-channels is that they are interchangeable.

Another prototype on this stand was that of a portable potentiometer with a single range extending from −0.05 mV to 100.05 mV, intended for testing thermocouples and associated indicators, recorders and controller. Yet a third new instrument was the pencil-type oscillograph galvanometer fitted with d'Arsonval type coils.

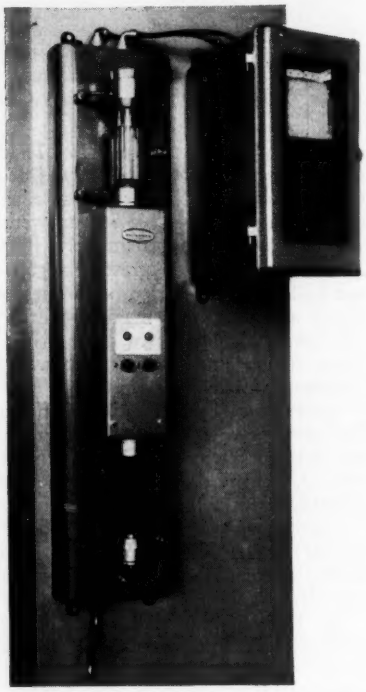
Space this year permitted the company to show their "Miroscan" X-ray analyser, the prototype of which was completed last year but due to space limitations had to be shown privately. One of the components of this instrument —the proportional counter used for detecting hard X-radiations—was shown as a separate item. It consists of a cylindrical ionization chamber filled with xenon, together with a small amount of ethyl formate for stabilizing gas multiplications.

Cawkell Research and Electronics

A closed circuit television monitor on which the picture may be "frozen" by operating a switch or depressing a button was one of the exhibits on the Cawkell stand. Called the Tele-Remscope TR1, it will operate on 405 or 625 lines, 50 fields/sec or 525 lines, 60 fields/sec and requires a positive-going 1.5 V p-p video input. Any number of fields from 1 to 4 may be stored and displayed for up to 15 min on the face of an English Electric 702 storage tube. Also new from the Cawkell workshops was the Young's Modulus Equipment, developed in collaboration with I.C.I. and Vacuum Research (Cambridge). This equipment, which is a prototype, measures the resonant frequency and damping capacity of an accurately made specimen in a vacuum and at temperatures of up to 1,000°C.

Ekco Electronics

Several prototype units were exhibited including a chromatogram scanner for identifying different radioisotopes mounted on strip paper, the new type N-676 scintillation counter designed for gamma spectrometry and the latest Ekco developments in the field of transistorized instrumentation for nuclear reactors—a reactor period meter, a logarithmic gamma health monitor and a shut-down amplifier. A new manual scaler, type N667, was shown, in association with a Type N662 round lead castle, a GM tube and Geiger pre-amplifier and there was the prototype of a new ancillary power unit designed to provide stabilized supplies of 300 V H.T. and 200 V to 3 kV for scintillation counters and their associated amplifiers.



This highly sensitive water contamination monitor was displayed by Elliott Nucleonics.

Electronic Instruments

The transistorized portable pH meter shown is an entirely redesigned model of an earlier unit. It has completely automatic temperature compensation from 0° to 100°C, for changes in both the pH/e.m.f. characteristic and the zero of electrodes, and is therefore comparable in performance to many mains operated laboratory pH meters.

Elliott Nucleonics

As little as 0.5 x 10^{-5} μc/litre of Sr^{90} in water can be detected above background counts by the water contamination monitor displayed by Elliott Nucleonics. The detection of such a low activity is achieved by concentrating the activity in an ion-exchange resin filter

through which known quantities of water to be tested are passed. The resin surrounds a G.M. tube and the signals obtained from this are amplified in order to energize a strip chart recording instrument.

E.M.I. Electronics

Among the new developments of this company shown were a single hand monitor designed for establishments where small quantities of radioactive materials are used and a low activity sample monitor. The hand monitor is transistorized and incorporates both audio and visual alarms. The sample monitor, which incorporates its own lead castle and end window geiger counter, is also transistorized and can be operated from either battery or mains.

A. Gallenkamp and Co. J. W. Towers and Co.

The manipulator glove box on this stand was developed for handling alpha and beta active substances in controlled atmospheres. Features are a rubber sealed top window and long gloves.

General Radiological

Among the range of portable instruments for health monitoring and survey work displayed by the Nuclear Engineering Division were a battery-operated scintillation dosemeter for measuring gamma and X-ray dose rates over a wide range of energies and intensities and a compact transistorized scintillation monitor for detecting and measuring gamma radiations down to background level. The first instrument consists of a plastic air-equivalent scintillator used in conjunction with an 11-stage photomultiplier tube. The output from the tube is applied to a 4-stage pulse amplifier followed by a special converter circuit and a 2-stage logarithmic d.c. amplifier. Four meter ranges are available in 10^1 increments for measurement of gamma and X-ray dose rates from 0.1 to 100 mr/h. Calibration accuracy is given as ±15% over the temperature range −10°C to 50°C and over the energy range 40 keV-3 MeV. The other instrument, scintillation monitor NE 148, provides three meter ranges: 0-0.03 mr/h; 0-0.3 mr/h; and 0-3.0 mr/h. It is designed to withstand rough usage and extreme climatic conditions.

Isotope Developments

For measuring mμc dose levels of low energy beta emitting isotopes, IDL have developed the coincidence scintillation counter type 2022. It incorporates two photomultiplier tubes which view a mixture of the sample with a liquid scintillator. The amplified signals from the tubes meet in a coincidence circuit where thermal noise is rejected. Background counts of approximately 1 count/s and efficiencies of about 12% are obtainable with tritiated water. The automatic sample handling and recording unit, type 2014, also shown, handles up to 50 standard 1 in and 2 in planchets which are offered in turn to a radiation detector and then restacked in their original order so that they may be remeasured for half-life assessments.

Marshall of Cambridge Electronics

Demonstrated was a transistorized counting and timing scaler containing a discriminator, six scaling decades and a power unit. The indication of count is provided on six meters. A variable paralysis time is incorporated in the discriminator, having a minimum value of 1 microsecond, and a comprehensive gating system is provided. Similar to Type 200, is the Type 201 scaler, which has, however, a minimum resolving time of 100 nanoseconds.

Metals Research

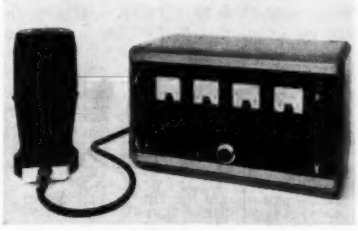
This company specializes in metallic single crystals and in the making of apparatus used in the processing of these crystals. Many types of crystals were displayed, together with pyrotubes capable of heating furnaces up to 1,800°C, and the "Servomet" spark machine. The latter is designed for rapid, accurate and strain-free machining of all types of metallurgical specimens.

Morgan Crucible Company

Thermocouples made of modified silicon carbide and of graphite were featured by this company. With these materials it is possible to produce couples capable of withstanding temperatures in the 1,600°C to 2,000°C range. Also demonstrated was the hot stage time lapse cine-microphotography technique developed for studying slow changes in the visible qualities of solid materials. The material is placed on an electrically heated metal strip and illuminated by ultra-violet light. A camera gun photographs the changes at minute intervals.

Nuclear Enterprises (G.B.)

Featured by this company was the NE 150 plastic scintillator developed in collaboration with a Harwell scientist. It is intended for use with pulse shape discrimination techniques, particularly for counting fast neutrons in the presence of large gamma ray fluxes. Also shown were specimens of the new range of crystal-photomultiplier assemblies where high quality inorganic scintillation crystals such as NaI (Tl), LiI (Eu) and CsI (Tl) are combined with specially selected EMI photomultipliers. On the instrument side Nuclear Enterprises exhibited a human body radiation monitor designed for the U.K. AEA and a fully transportable radio-iodine environmental monitor.



A fully transportable radio-iodine environmental monitor developed by Nuclear Enterprises (G.B.).

Paton Hawksley Electronics

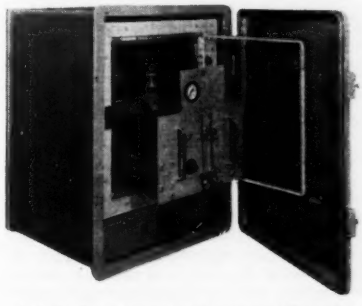
A new range of instruments for metrological work was displayed. These instruments transduce dark/light pulses from cross diffraction gratings into suitable signal material for processing by digital counter or servo mechanisms.

W. R. Prior and Co.

The latest design of the Prior metallurgical microscope was exhibited. The illuminating system is built into the body tube employing two iris diaphragms and a redesigned condenser system. All optics have coated surfaces and are corrected for uncovered specimens.

W. G. Pye and Co.

The Pye Process Analyser shown detects trace components present in gases of less than one part in a million. Easily adapted, it can be used in conjunction with column switching, sample selection and the back-purging of unwanted components. In addition to a robust detection system, it incorporates an automatic sampling valve designed and patented by the I.C.I. Billingham Division. Also new among the W. G. Pye exhibits was the fully sealed pH electrode unit designed for use in open tanks, channels and troughs.



W. G. Pye showed this process analyser which can detect trace components present in gases of less than one part in a million.

Townson and Mercer

The latest version of the Townson and Mercer flexible handling cabinet, designed for welding, included a rigid frame for supporting the cabinet internally. Also on show was their glove box improved with a more streamlined appearance.

Technical Papers and Publications

THE INSTITUTION OF MECHANICAL ENGINEERS (in conjunction with the B.N.E.C.)

Symposium on the Dounreay Fast Reactor

THE Dounreay Fast Reactor was described in *Nuclear Engineering* for June and July, 1957. While this description was fairly full and, in fact, gave practically all the information available at that date, there was, of course, much that was then " under wraps " as well as the subsequent modifications. The star-shaped prism comprising the core tube nest was subsequently described in the issue of November, 1958 (p. 494). The symposium was, however, the occasion for releasing a great deal of additional information; the list of papers gives some idea of the ground covered.

List of Papers

1—**Introductory paper.** R. Hurst and R. V. Moore.

2—**Design and construction of the core, reactor vessel, fuel handling equipment and shielding.** J. Tatlock, A. G. Evans, P. K. Richards and R. Bellinger.

3—**Design and construction of the heat-transfer circuits, steam-generating plant and reactor-control systems.** R. R. Matthews, W. G. Hutchinson, P. K. Richards, A. S. Fenemore and M. H. Ewbank.

4—**Dounreay Fast Reactor metallurgical problems.** C. R. Tottle, D. S. Oliver and K. Q. Bagley.

5—**Dounreay Fast Reactor physics.** R. D. Smith and D. C. G. Smith.

6—**Testing, commissioning and initial operation of the Dounreay Fast Reactor.** J. L. Phillips, R. R. Matthews and W. J. M. Davies.

Two of the most interesting features of the general reactor design (Paper 2) were the comparison of different coolant behaviour and the fuel element design. As is generally known, the coolant selected for final use is sodium but, for operational convenience, the 70/30 NaK alloy is being used at present. Table 1 gives a comparison of a number of cooling media, from which it would appear that lithium has very attractive properties from the viewpoint of pure heat transfer, but it is extremely corrosive, and its cost is prohibitive.

Fuel elements were briefly described in a 1958 Geneva paper (274, Cartwright *et al*) but there have of course, been modifications since that time and, in fact, changes in the fuel alloy are announced for the near future. Fig. 1 shows the element details. The breeder end pieces are natural U, beta-quenched for fine grain size to prevent wrinkling. The fuel, inserted in seven pieces, is 45% enriched U, alloyed with 0.5 at.% chromium. It has been announced, however, that a new core alloyed with molybdenum in place of chromium may be fitted at a later date.

As is generally realized, the design of the fuel element had to take into account the possibility of a melt-down. The element is hollow, and by making the inner tube melt before the outer, there was a reasonable chance that the outer tube would survive long enough to guide the molten fuel towards the catch-pots at the bottom of the tank, instead of risking the formation of super-critical agglomerations within the core itself. Niobium was used for the outer tube, and vanadium for the inner; both these metals necessitated a heavy development programme which is more fully dealt with in Paper 4. The manufacturing methods used for the outer tube are of interest. As will be seen from Fig. 1, the outside has intermittent helical finning, with the object of preventing the element touching the adjacent one, in case of bowing during service, and restricting the coolant flow. This configuration was obtained by drawing a niobium tube with straight external fins, twisting it to produce the correct helix angle, and machining off the unwanted portions. The critical design figures in the centre fuel element are 840° C maximum U temperature, and 610° C and 515° C for the maximum interface temperatures between coolant and inner and outer tubes, respectively.

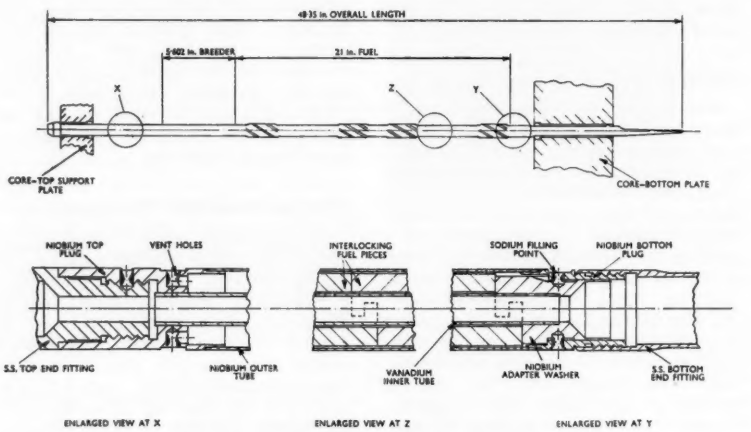


Fig. 1.—Details of Dounreay fuel element.

Fuel changing is carried out under shut-down conditions, via a " canning station " located on the main floor level, just outside the circular rails for the Goliath crane. The canning station consists of two compartments, connected by a valve. One compartment contains a horizontal rotating magazine holding 32 new fuel elements in lead-lined stainless-steel cans, the other contains a shielded trolley which accepts a can in the horizontal position, through the valve, pivots it into the vertical position, and can be traversed to any of three valves in the top of the canning station or to a " lidding " device. The three valves are for accommodating two charging machines and a transit flask. New elements are loaded into the charging machine via the trolley, irradiated elements are received from the charging machine directly into stainless-steel cans. These are lidded and the lid brazed on (by induction heating) after which the can is transferred to the transit flask, for conveyance to the cooling pond.

In all, there are some 11 different types of unit which may require removal for maintenance or replacement, and 7 different types of flask have been developed to handle them.

Table 2 gives general data on the core and breeder units.

Table 1. Comparison of liquid metals (Paper 2)

Coolant	Na	K	NaK	Li	Pb	Bi	Pb-Bi (eut.)	Hg
*Equivalent, limiting velocity ft/sec	35	38	38	47	10	11	10	9
Limiting heat transport, c.h.u./ft °C sec for 4-in pipe	3.4	1.9	1.2	8.8	1.2	1.3	1.2	1.4
Pumping Power ($1/\rho^2c^8$)†	47	292	78	4.2	178	238	223	169
Melting Point, °C	98	64	40	186	327	271	125	−39
Boiling Point, °C	883	760	825	1,317	1,717	1,477	1,670	357
Cost, £/ft³	3	42	16	120	40	500	300	370

* Limiting velocity is that at which cavitation commences.
† ρ is the density and c the specific heat.

Metallurgical Problems

Examining the Dounreay scheme as a whole, one realizes throughout that metallurgical considerations were of paramount importance from the first. Two main problems presented themselves; the development of suitable canning materials, and the question of coolant—both problems being inter-related. At the same time, the feasibility of liquid metal had to be considered from other standpoints than that of pure compatibility with the fuel elements, and the Dounreay story is one of close co-operation between metallurgists who indicated what could be done and what was necessary, and engineers who set out to realize the requirements. As Paper 4 points out, although the absolute solubility of a particular element in liquid metal may be minute—only a few ppm—severe corrosion may occur in dynamic systems by mass transfer; an example being the transfer of carbon from low alloy to stainless steels.

Corrosion rates are extremely sensitive to

Table 2. Core and Breeder Data (Paper 2)

Core	
Core power	60 MW(th)
Number of fuel elements	367
Heat transfer surface	168 ft²
Average heat flux	680,000 Chu/h ft²
Maximum to average heat flux	1.7
Power density (per unit volume of core)	14,250 kW/ft³
Specific power	286 kW/kg U^{235}
Coolant inlet temperature	200°C
Coolant outlet temperature from core	400°C (mean)
Diameter of core	21 in
Length of core	21 in
Core NaK flow rate (excluding by-pass flow)	584 lb/sec
Coolant flow area	0.694 ft²
NaK velocity	15.8 ft/sec
Pressure drop across the core	11 lb/in²
Core composition :	
U^{235}	9.3% vol.
U^{238}	22.7% vol.
Nb	5.5% vol.
Va	1.9% vol.
S.S.	19.1% vol.
NaK	41.5% vol.
Fuel (o.d.)	0.698 in
Fuel (i.d.)	0.316 in
Outer tube (o.d.)	0.752 in
Outer tube (i.d.)	0.712 in
Inner tube (o.d.)	0.298 in
Inner tube (i.d.)	0.258 in
Maximum outer tube temperature	550°C
Maximum inner tube temperature	680°C
Maximum uranium temperature	840°C
Breeder	
Breeder power (corresponding to 60 MW(th) from core)	12 MW(th)
Number of breeder elements	1,872
Heat transfer surface	4,420 ft²
Average heat flux	5,150 Chu/h ft²
Coolant inlet temperature	200°C
Coolant outlet temperature	350°C (mean)
Diameter of breeder	74.6 in
Length of breeder	84 in
Breeder NaK flow rate	156 lb/sec
Coolant flow area	8.1 ft²
NaK velocity (inner region average)	0.5 ft/sec
Breeder composition (average, percentage varies radially):	
U^{235}	0.4% vol.
U^{238}	60.1% vol.
S.S.	9.5% vol.
NaK	30.0% vol.
Fuel outside diameter	1.277 in
Clad, inside diameter	1.290 in
Clad thickness	0.036 in

impurities, of which oxygen has probably the most deleterious effects. In the early stages it was considered that oxide concentration in the liquid metal could be sufficiently reduced by cold trapping; i.e., by reducing the temperature at one part in the circuit to below the temperature at which sodium oxide is soluble in sodium, assisting the precipitation of oxide by the provision of a large surface area such as wire mesh or Raschig rings. By cooling to 100°C, oxygen levels in sodium circuits have been reduced to 5 ppm, although the clean-up period may be several weeks, even in small circuits. It was later decided that this degree of purity was insufficient, and that it was necessary to resort to hot trapping, in which the oxygen is removed by a zirconium "getter" at 600°C-700°C, in addition. The original design utilized a cold trap in each primary circuit; the space in the vault was insufficient to accommodate hot traps as well, and it was decided to replace 5 cold traps by 5 hot traps, to be brought into use when the cold traps had done their work.

Testing and Commissioning

The modification to the trapping system, which was only decided upon in the summer of 1957, naturally caused a setback in the programme, which called for completion by January of 1958. Additional changes taking place at the same time were the modification of the core tube nest to prevent instability due to minute movements of the fuel elements, and the alterations to the catch-pot arrangements at the bottom of the tank, to ensure that, in case of a melt-down, enriched fuel would be held in sub-critical masses.

The first important test to be carried out was the pressure and vacuum testing of the sphere and air-lock, which took place in May, 1957. An initial test was run at 5 p.s.i. to check the movement of two portions of the upper hemisphere which were slightly out of round; this was found to be only $\frac{1}{4}$ in. A vacuum test was then applied at 10.7 p.s.i.a., after which the main test at 20 p.s.i. internal pressure was successfully applied.

The precautions taken to ensure quality of welding of the reactor circuits were formidable. Each welder had to perform three consecutive flawless joints in each size of pipe; vertical and horizontal welds were required under difficult conditions; an absence of one week necessitated a modified test for requalifying. The total number of welds within the sphere was 6,096; in all there were 7,846. The number of X-rays taken was 18,500. The effectiveness of these stringent methods can be seen by the final leakage rate of the primary circuit which was 0.54 in w.g./day; this can be better appreciated when it is considered that a 0.015-in hole in the primary circuit would give a leak rate of 1 in w.g./hour. Dry testing was carried out during 1958, and was completed by June, 1959, when charging with NaK began.

Coolant Charging

Preparation of the charge had been in progress for about seven months, and had presented a number of difficulties. Melting was carried out in the liquid metal station; the alloy was filtered before transfer to the heated storage tanks. Transfer was by means of nitrogen pressure; the limit of 3 p.s.i. on some of the containers combined with the dirty condition of some of the metal led to endless difficulties in build-up of blockages in pipelines, necessitating modifications to pipe-work to provide for rodding and, in certain cases, to the provision of complete standby sections of pipe, so that one set could carry on while the blocked section was removed for clearing.

Before charging, circuits were purged, first with commercial nitrogen and then with nitrogen having an oxygen content of less than 30 ppm. Steam was injected into the secondary heat exchangers to assist the trace heating. Several of the secondary circuits were filled before the primary, which was heated to 120°C, the metal being over 110°C, in case there was unalloyed sodium present.

The metal was circulated in the primary circuits for about 12 hours by the electromagnetic pumps, after which it was returned to the storage tanks and allowed to fall to 80°C before being returned to the circuit through the filter. It was considered that this should have cleaned up the circuit from any dust and the amount of oxide would have been very small. This, however, was not realized. Clean-up started with five days' circulation, during which it was found that the flow rates through the cold traps were much lower than expected (300 lb/h average, 1,200 lb/h max. as against 2,700 lb/h design figure). Improvements were made by raising the level of the metal by 1.7 in, and raising the temperature to above 170° C.

"Teething Troubles"

At this stage the first testing of the control-rod mechanisms took place; this had not been previously possible because their functioning depended on the presence of liquid metal in a dash-pot. Only six out of the 12 units would function; apparently the screw mechanism was jammed with oxide. A further 18 days' cold trapping took place with an average flow of 1,800 lb/h through the traps; it was subsequently found that the metal was still not free of particulate matter.

Freeing of the control units took considerable time and ingenuity; a viewing device was first made to allow of inspecting the liquid metal surface in the control tubes; this was later developed into a glove-box device through which could be passed various devices to clean up the oxide from the joint faces, and from the surface of the metal. A hand-operated direct drive to the control mechanism, passed through a gland in the viewing device, allowed most of the mechanisms to be freed with a torque of about 30 lb-ft; subsequent electrical operation was possible with a more normal torque of 1 lb-ft.

Trouble was also experienced with the liquid metal seals of the rotating shields. Although the blanket gas pressure is reduced to 0.5 p.s.i. at shut-down when these seals are brought into use, a certain amount of bubbling and splashing had taken place resulting in the contamination of a mercury seal with sodium, and the formation of a high-melting-point alloy, freezing the shield. Freeing of this was carried out by loading of mercury and removal of alloy in stages; over a ton of mercury was loaded into and out of the seal before it was finally freed. The seals were subsequently modified.

In spite of all these difficulties, the reactor was loaded to criticality and a zero-energy programme (less than 50 kW) was completed by April 1960, when the reactor was shut down for installation of a modified core tube nest which would give facilities for irradiation testing of fuel elements for a future prototype reactor.

THE IRON AND STEEL INSTITUTE

Symposium on Steel for Reactor Pressure Vessels

(*Continued from page* 39)

Corrosion by Sodium

Dr. C. Tyzack in his paper on the "Corrosion of Iron and Steel in Liquid Sodium" chose to divide the two types of loss into solution processes and mass transfer. In isothermal conditions iron will dissolve until equilibrium conditions are reached, the rate, although not the concentration, being determined by the oxygen level. In a reactor system, however, with temperature gradients around the circuit the changing solubility can result in mass transfer, in spite of the low solubility of iron in sodium, viz.: 0.025 ppm at 800°C and 0.0046 ppm at 400°C. Although the mass transfer may not itself be important, the build-up in parts of the circuit of corrosion products can be particularly embarrassing. It has been shown that the two critical isotopes are iron-59 and then chromium-51.

The rôle of oxygen is a key one in understanding the corrosion mechanism of many materials in liquid sodium. Because of this, great care has been taken in the measurement of the oxygen solubility which has been established by Culcheth and is shown

in Fig. 1. The large temperature dependence is used to control the oxygen content in the DFR, cold traps packed with steel wool and operating in the temperature range of 120°-150°C being successful in lowering the oxygen level to around 5 ppm. To go below this figure, however, it is necessary to use hot gettering with beryllium or zirconium.

At first sight, as the free energy values for the iron oxides are so much higher than the sodium oxides it seems strange that sodium should corrode steel at all, but Horsley of Harwell has demonstrated the existence of a ferrate the successive production and reduction of which may be the mechanism of mass transfer. For the study of such a process it is clearly essential to operate in loops, static tests giving rise to quite misleading results. On the other hand the chromium oxide layer, the protective barrier on stainless steel, should be unstable below 550°C and it is possible that a complex chromium compound may be protecting the stainless steel. It is possible therefore that there is an optimum oxygen level in the system for the operation of stainless steel circuits but this is yet to be determined.

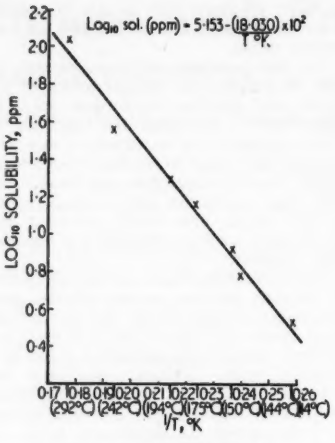


Fig. 1.—Solubility of oxygen in sodium.

Carbon is very slightly soluble in sodium (74 ppm at 700°C) and contamination of the circuit could be particularly important as it may give rise to carburization of austenitic stainless steels, extensive carburization causing embrittlement and increasing the susceptibility to fatigue failure. This would be particularly embarrassing in such components as fuel elements. On the other hand decarburization of ferritic steels should they be used with sodium circuits is a very real problem although 1 and 2¼% chromium steels appear promising. The use however of both austenitic and ferritic steels in the same circuit raises important questions.

The effect of nitrogen also must be considered as it is used as a blanket gas over dynamic sodium circuits and this may lead to nitriding at certain temperatures, the general effect being to decrease the ultimate tensile strength and decrease the ductility. It is difficult however at the present stage to assess the relevance of results obtained to reactor operation.

NEW BOOKS

Reactor Handbook (Second Edition) Volume 1. Materials. Edited by C. R. Tipton, Jr. (Battelle Memorial Institute). 1,207 pp., Interscience Publishers, New York and London, 260s.)

This is the modernized form of a work which appeared about eight years ago, and contained data compiled during the period of about 12 years' intensive work which followed the original Chicago Pile. To say that a considerable amount of data has been released since then is a noteworthy understatement. Even with the size of the present volume available, the task of selection must have been no easy one; it takes three pages to list the 118 contributors.

The information is sectionalized in a very logical and satisfying way. Part A, the General section, contains articles on health, safety, and storekeeping problems for source and special materials; generalities of radiation damage; separation of heavy and light water; separation of zirconium and hafnium; radiation damage in miscellaneous materials.

Part B is devoted to fuel materials; Part C to cladding and structural materials; D to control materials and burnable poisons. Part E covers moderators; F, coolants; the final section, G, is devoted to shielding materials. An appendix devotes some 30 pages to listing references of published constitutional diagrams of binary alloy systems.

N.E.T.S.

The "Advance" Science Masters Handbook. Ivan L. Muter, B.Sc., A.M.I.E.E., A.Inst.P. (124 pp., 150 illus. Advance Components, Ltd. (Roebuck Road, Hainault, Essex). 12s. 6d.)

The hospitality of these columns is seldom extended to manufacturers' publications. Book publishing is an ancient, honourable (and, nowadays, arduous) calling, and it appears only fair to limit reviews to books that are published as such, and to exclude those having an ulterior (or, in the present case it might be more appropriately termed a "side-band") motive. Nevertheless, in this instance the side-band can be considered sufficiently vestigial to justify its inclusion.

The book originated in a series of data sheets giving details of various experiments which could be performed with a few basic pieces of test gear, to demonstrate lecture theory. The demand for these proved so substantial that the author (senior lecturer in electrical engineering at Rotherham Technical College) was commissioned to prepare a book containing a series of experiments covering general electronics, sound, and wave motion, with relevant facts and figures, which would be of value to all science teachers. There is little doubt that it will not only achieve this, but will prove of interest to many others wishful to brush up their knowledge, and fill in the gaps. The sole criticism which the present reviewer would offer is that one is plunged rather sharply *in medias res*; a few more definitions would help.

J.A.B.-B.

Introduction to Atomic Energy. By William G. Atkinson, (68 pp., 30 illus. John F. Rider, New York. Chapman and Hall, Ltd., 11s.)

This little book is rather interesting in that it sets out to help those who need to know a very little about nuclear work, and makes the hard bits comparatively easy, without ignoring them altogether. There have been a number of books written with the object of assisting the beginner, but most of them are written in a more popular style. For example, we have not before seen a book of this length attempt to explain resonance capture.

The author, who is instructor in elementary nuclear physics, and chief hull designer to the Groton submarine shipyard of General Dynamics Corporation, developed this book from a series of instructional programmes (in conjunction with the design of *Nautilus*) to give some idea of basic principles to those who were involved in ancillary work. In our opinion, he has succeeded remarkably well.

MEETINGS

February 6.—The Society of Instrument Technology (Data Processing Section, London, at Manson House, 26 Portland Place, W.1. 6.30 p.m.). **The Universal Decision Element,** Prof. J. E. Parton, Ph.D., M.I.E.E., and A. Rose, M.Sc.

February 9.—The Society of Instrument Technology (Cheltenham Section, at the Belle Vue Hotel, Cheltenham, 7.30 p.m.). **Instrumentation at Berkeley Power Station.** F. J. Benstead.

February 16. — The Institution of Electrical Engineers (at the Central Hall, Westminster, London, S.W.1). The Faraday Lecture. **Transistors and All That.** L. J. Davies, C.B.E., M.A., B.Sc., M.I.E.E. (Admission by ticket only, from the I.E.E.)

February 17.—The Institution of Structural Engineers (The Scottish Branch, at The Institution of Engineers and Shipbuilders, 39 Elmbank Crescent, Glasgow, 7 p.m.). **The Development of Nuclear Power in the United Kingdom.** T. C. Waters, M.I.Struc.E.

February 22.—The Society of Instrument Technology (South Wales Section, at the Newport and Monmouthshire College of Technology, Newport, 6.45 p.m.). **The Manufacture, Properties and General Uses of Metal Bellows.** R. W. Houghton.

February 22.—The Institution of Mechanical Engineers (at 1 Birdcage Walk, London, S.W.1. 6 p.m.). The Thomas Hawksley Lecture, **Prospects of Fusion Power.** Prof. P. M. S. Blackett.

February 28.—The Institute of Marine Engineers (Joint Panel on Nuclear Propulsion, at 76 Mark Lane, London, E.C.3). **Lloyd's Register of Shipping Rules for a Nuclear Ship.** J. M. Murray, M.B.E., and H. N. Pemberton.

Books Received

Transport Phenomena. By R. Byron Bird, Warren E. Stewart, and Edwin N. Lightfoot. (780 pp., John Wiley and Sons, Ltd., 110s.)

Grundzüge der Strahlenschutztechnik. By Thomas Jaeger. (392 pp., Springer-Verlag, Berlin, DM.46.50.)

Nuclear Propulsion. Edited by M. W. Thring. (300 pp., Butterworths Publications, Ltd., 50s.)

TRANSLATIONS

A Résumé of Principal Articles

Le Réacteur a Eau Bouillante de Kahl (56)

L'article auquel Allgemeine Elektrizitats Gesellschaft a contribué, décrit la conception de la centrale, en mettant un accent spécial sur le génie civil, les circuits de vapeur, les éléments de combustible, le coeur du réacteur et la commande des barres de contrôle. Une vue d'ensemble de l'intrumentation et du programme de travaux est également donnée. Il s'agit donc d'un compte rendu général relatif à la centrale de 15 MW qui a été critique pour la première fois le 13 Novembre et qui est présentemente montée en puissance.

L'utilisation de combustibles aux plutonium dans les réacteurs commerciaux (66)

Dans les réacteurs compacts, tels que ceux qui sont utilisés pour la propulsion des navires, il faut que la réactivité initiale soit suffisante pour faire face à l'empoisonnement dû au xénon, et pour permettre une longue durée d'utilisation du combustible. Il faut néanmoins que le pilotage du réacteur soit sûr et ce probléme est délicat à résoudre. Ceci a conduit à utiliser des poisons consommables qui sont difficiles à incorporer et dont l'action est difficile à contrôler.

Le plutonium produit dans les centrales nucléaires civiles du Royaume-Uni contient une quantité appréciable de plutonium-240. L'article examine les implications sur la réactivité de l'addition de ce plutonium, pour l'enrichissement du combustible des réacteurs modérés à l'eau lourde. En supposant que la section efficace neutronique de cet isotope varie dans des limites appréciables, il est montré qu'il est possible, dans tous les cas, de choisir des additions qui permettront de construire un coeur facile à contrôler et de vie pratiquement indéfinie.

Les contraintes thermiques dans le béton (69)

Des essais ont été entrepris par Simon Carves, pour mesurer les contraintes thermiques qui prennent naissance dans des poutres en béton soumises à des gradients de temperature. Ces recherches ont pour but d'estimer les effets de l'énergie absorbée dans le béton utilisé soit comme blindage thermique, soit comme caisson sous pression. Les essais effectues sont décrits et il est donné une vue d'ensemble des premiers résultats obtenus.

Générateurs à basse fréquence (75)

La commande des barres de contrôle est généralement assurée par des moteurs synchrones à basse fréquence. Le présent article décrit un procédé de production de basses fréquences par des moyens essentiellement statiques, ce qui permet d'éliminer l'utilisation des changeurs de fréquence habituels. Cette méthode semblerait produire un courant parfaitement régulier, ce qui eliminerait en particulier le risque de blocage des moteurs commandant les barres de contrôle.

Jauges Pneumatiques pour Mesures en Pile (77)

L'utilisation de jauges pneumatiques pour des mesures de mouvements linéaires avec grande précision et stabilité dans des régions à haute température a été vérifiée par des expériences. La jauge a de faibles dimensions ce qui la rend idéale pour l'utilisation en pile. Les résultats d'essais de sensibilité et de stabilité jusqu'à des températures de 400°C sont donnés. Les recherches effectuées jusqu'ici laissent supposer que les performances seront satisfaisantes à des températures très supérieures à 400°C, le but initial.

Der Siedewasser-Reaktor von Kahl (56)

Der Artikel, der ein Beitrag der Allgemeinen Elektricitäts-Gesellschaft ist, diskutiert die Konstruktion des Werkes mit besonderem Hinweis auf die baukonstruktiven Arbeiten, die Dampf-Umläufe, die Brennstoff-Elemente und den Reaktorkern und die Kontrollstab Antriebe. Eine kurze Zusammenfassung der Instrumenten-Anlage ist beigefügt und ein kurzer Bericht über die eingehaltenen Bautermine. Es ist ein allgemeiner Bericht über das 15 MW-Werk, das zum ersten Mal am 13. November kritisch wurde und das jetzt zur Kraftlieferung hochgebracht wird.

Die Verwendung von Plutonium als Brennstoff in Betriebs-Reaktoren (66)

Eines der grossen Probleme in kompakten Reaktoren für beschrankten Raum, wie sie für den Antrieb von Schiffen benutzbar sein würden, ist dasjenige, genügend Reaktivität aufzubauen, um die Wirkung von Xenon zu überkommen und eine lange Dauer des Kerns zu erreichen, wobei jederzeit volle Kontrolle bestehen bleiben soll. Dies hat dazu deführt, verbrennbare Gifte zu verwenden, die aber schwierig einzubringen sind, und deren Wirkung schwierig zu kontrollieren ist.

Plutonium, wie es in den britischen nicht-militärischen Reaktoren erzeugt wird, wirdun eine nicht unerhebliche Quantität von Plutonium 240 enthalten. Der Artikel befasst sich mit den Folgen für die Reaktivität, wenn dieses Plutonium zur Anreicherung in einem mit schwerem Wasser moderierten Reaktor zugesetzt wird. Es wird gezeigt, dass sogar, wenn weitgehendst verschiedene Annahmen für den Neutronen-Querschnitt des Isotops gemacht werden, Zusätze gewählt werden können, die einen eicht kontrollierbaren Kern von sozusagen unendlicher Lebensdauer ergeben werden.

Wärme-Beanspruchung im Beton (69)

Im Himblick auf die Bewertung der Wirkung absorbierter Energie in Beton, der als thermischer Schirm oder alternativ als Druckgefäss benutzt wird, sind Experimente bei der Firma Simon Carves ausgeführt worden, bei denen man die Wärme-Beanspruchungen gemessen hat, die in Betonbalken auftreten, die Temperaturschwankungen ausgesetzt sind. Die Gesamtreihe der durchgeführten Experimente wird beschrieben, und die vorläufigen Ergebnisse werden diskutiert.

Niederfrequenz-Generatoren (74)

Für die Betätigung der Kontrollstäbe werden Niederfrequenz-Synchron-Motoren bevorzugt. Der Aufsatz bringt die Beschreibung eines Schemas zur Erzeugung niedriger Frequenzen mittels einer im wesentlichen statischen Einrichtung, sodass normale Frequenzwandler unnötig sind. Die Methode soll eine besonders reine Form der Welle erzeugen und auf diese Weise die Gefahr des " Hakens " der Kontrollstab-Motoren ausschalten.

Pneumatische Anzeigeapparate für Messungen im Inneren des Kerns (77)

Die Wahl von pneumatischen Anzeigeapparaten für die Messungen linearer Bewegungen, die grosse Sensitivität und Stabilität in hohen Temperaturbereichen aufweisen, ist experimentell als richtig bestätigt worden. Der Apparat is von kleiner Grösse, was ideal ist für die Verwendung im Inneren des Kerns. Es werden die Resultate für Prüfungen der Sensitivität und Stabilität bei Temperaturen bis 400°C gegeben. Bisherige Arbeiten lassen vermuten, das zufriedenstellendes Funktionieren bei Temperaturen weit höher als die augenblicklich gesetzte Grenze von 400°C erwartet werden kann.

El Reactor de Agua Hirviente en Kahl (56)

Este artículo, contribuido por Allgemeine Elektricitats-Gesellschaft discute el diseño de la central, con particular referencia a la ingeniería civil, los circuitos de vapor, los elementos de combustible y núcleo de reactor y los mandos de las barras de regulación. Se ofrece un breve sumario de la instrumentación y un cortó informe sobre el programa de construcción. Este es un informe general sobre la central de 15 kW que se volvió crítica por la primera vez el 13 de noviembre y que ahora se está preparando en etapas para alcanzar los MW previstos.

El Uso de Combustibles de Plutonio en Reactores de Producción (66)

Uno de los grandes problemas en reactores compactos tales como los se usarían en una unidad de propulsión de buques es el de generar una reactividad suficiente para dar una nulificacion parcial de zenón y una larga duración de núcleo y que a la vez sea completamente controlable. Esto ha inducido el uso de venenos quemables que son difíciles de incorporar y cuya acción es difícil de controlar.

El plutonio según producido en los reactores civiles del Reino Unido contendrá una significante cantidad de plutonio-240. Este artículo examina las implicaciones de reactividad en agregar este plutonio como enriquecimiento en un reactor moderado a agua pesada. Se señala que aunque se hagan presunciones considerablemente variadas para la sección transversal neutrónico del isotopo, se pueden seleccionar agregados que darán un núcleo fácilmente controlado y de una duración virtualmente indefinida.

Esfuerzos Termicos en Hormigón (69)

Con miras de hacer un aprecio del efecto de la energía absorbida en el hormigón empleado como una pantalla térmica o alternativamente como un recipiente a presión, se están llevando a cabo experimentos por Simon Carves para medir los esfuerzos térmicos que surgen en las vigas de hormigón sujetas a desniveles de temperatura. La serie de experimentos llevados a cabo se describen y se incluye una discusión de los resultados preliminares.

Generador de Baja Frecuencia (75)

Para operación de barras de regulación de reactores, se prefieren motores sincrónicos de baja frecuencia. Este artículo ofrece una descripción de un sistema para la generación de bajas frecuencias por medios que son esencialmente estáticos, así prescindienco de los cambiadores de frecuencia normales. Se dice que este método provee una forma de onda muy pura, así eliminando el riesgo de " cogging " (sacudimiento) de los motores de las barras de regulación.

Calibradores Neumaticos para Mediciones interiores en Reactores (77)

La selección de calibración neumática para mediciones de moción lineal de elevada sensibilidad y estabilidad en zonas de alta temperatura ha sido verificada por experimentación. El calibrador es pequeño en tamaño lo que hace que sea ideal para uso interno en reactores. Los resultados de los ensayos de sensibilidad y estabilidad hasta 400°C son ofrecidos. Las labores llevadas a cabo hasta la fecha sugieren " performance " satisfactorio a temperaturas muy por encima de la meta de 400°C.

Personal

Appointments

In addition to appointing a new director general (**Professor V. F. Weisskopf,** as reported in last month's "World Digest") the CERN Council at their December, 1960, meetings, had the task of electing new officers. **M. Jan Willems,** director and senior vice-president of the National Foundation for Scientific Research, Belgium, was elected president in succession to **M. Francois de Rose,** of France, who held this office for three years. **Professor Edoardo Amaldi,** director of the Institute of Physics, Rome, and **Mr. Jan Hendrik Bannier,** director of the Netherlands Organization for the Development of Pure Research, were elected vice-presidents. **Professor Cecil Powell,** Melville Wills Professor of Physics, Bristol University, succeeds Professor Amaldi as chairman of the scientific policy committee and **Dr. W. H. Alexander Hocker,** deputy director in the Bundesministerium für Atomkernenergie und Wasserwirtschaft, Bad Godesburg, succeeds Mr. Bannier as chairman of the finance committee.

Professor F. Ippolito.

Dr. W. E. Parkins.

Professor Felice Ippolito's appointment as secretary-general of the National Committee for Nuclear Energy for the period 1960-64 was recently confirmed by the CNEN Steering Committee.

Dr. William E. Parkins, formerly director of Atomics International organic reactors department, becomes associate technical director of the organization. In this capacity he will be partly responsible for the direction of AI's development programmes.

Mr. M. C. Timbs, an assistant secretary in the Prime Minister's Department, Australia, to deputize as executive commissioner of the A.AEC during the absence in Vienna of Mr. A. D. McKnight, recently elected chairman of the IAEA.

Dr. Ned S. Rasor, leader of the ion and electron physics group at Atomics International, becomes the director of the newly formed Energy Conversion Department. **Dr. Donald E. McKenzie,** leader of the chemistry research group, becomes associate director.

Dr. Bernard Gross, consultant to the IAEA on conference, publishing, documentation and library matters, has been offered the directorship of scientific and technical information at the agency. Since 1958 Dr. Gross has been a member of the agency's scientific advisory committee.

Sir John Wrightson, chairman and managing director of Head Wrightson and Co., to the board of A. Reyrolle and Co.

Professor V. F. Weisskopf.

M. Jan Willems.

Professor E. Amaldi.

Mr. Jan Bannier.

Major-General Sir Charles Dunphie, chairman of the Vickers-Armstrongs companies and managing director of Vickers, as deputy chairman of Vickers.

Mr. J. P. V. Woollam, a joint managing director of Simon-Carves, as deputy chairman.

Sir Josiah Eccles, deputy chairman of the Electricity Council, as director of the National Industrial Fuel Efficiency Service.

Sir Gordon Radley, former director-general of the G.P.O. and a director of four companies in the English Electric group, to the board of English Electric.

Mr. Peter Wrightson, vice-chairman of Head Wrightson and Co., as chairman of Head Wrightson India. Managing director of this new company is **Mr. Vaughan Pendred.**

Brigadier General Austin W. Betts, director of the advanced research project agency of the U.S. Defense Department, as director of the AEC's division of military applications. He succeeds **Major General A. D. Starbird,** who was appointed to this post in 1955. General Betts was at one time an associate director at Los Alamos.

Awards

Sir John Cockcroft is to receive the 1961 Henry Ford "Atoms for Peace" award. The presentation will be made at the M.I.T., Cambridge, Mass, on April 6. Monetary value of the award is £26,785.

Vice-Admiral Hyman Rickover is to receive the Distinguished Service Medal, the highest peacetime award in the U.S. The presentation will take place aboard U.S.S. "Nautilus."

The thousandth IAEA Fellowship to be awarded has gone to **Dr. Lionel P. P. G. Siriwardene,** of Ceylon. He will use it to undertake training at the Isotope School, Harwell.

Mr. Casper W. Ooms, legal expert on patents who has been a member and chairman of the U.S. AEC patents compensation board since it was established in 1947, has been awarded the first U.S. AEC Citation, in recognition of his "outstanding and devoted service to the Commission and his country in an activity which vitally affects the national defence and the civilian atomic energy programme."

New Year HONOURS

BARON

Sir Alexander Fleck, chairman of advisory council on research and development, Ministry of Power, and of the Nuclear Safety Advisory Committee.

BARONETS

Mr. Cecil Dannatt, vice-chairman of AEI.

Mr. K. R. Pelly, chairman of Lloyd's Register of Shipping.

Professor B. W. Windeyer, Professor of Radiology, London University.

C.M.G.

Professor S. Sunderland, chairman of the National Radiation Advisory Committee, Australia.

G.B.E.

Sir Ellis Hunter, chairman of Dorman Long and Co.

C.B.E.

Mr. C. W. Goodman, chairman and managing director of the English Electric Company of Australia.

Mr. E. F. Newley, deputy director of AWRE, Aldermaston.

Mr. J. R. Pheazey, vice-chairman and joint general manager of Standard Telephones and Cables.

Mr. J. B. Scott, sales director of Crompton Parkinson.

Mr. Cecil Dannatt.

Mr. E. F. Newley.

O.B.E.

Mr. J. Black, works manager, ICI, Mossend.

Mr. W. N. Clinch, controller of the CEGB, Eastern Division.

Mr. W. R. Harvey, manager of marine division, Babcock and Wilcox.

Mr. G. D. Ireland, chief engineer, Windscale and Calder Works.

M.B.E.

Mr. W. J. Neal, chief fire officer, AERE, Harwell.

Mr. C. Sanders, senior experimental officer, AERE, Harwell.

B.E.M.

Mr. W. Crone, works fire brigade officer, Windscale.

Mr. E. Shepherd, research and experimental mechanic chargehand, AWRE, Aldermaston.

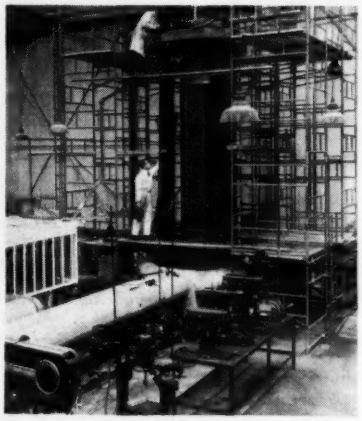
Industrial Notes

Sir Lindsay Parkinson and Co. are to undertake river works and site preparation for the CEGB nuclear station to be built at Oldbury, Gloucestershire. Value of the contract is £2.2 million. The river work includes the construction of a reservoir on the Severn foreshore, for cooling water supplies.

Mullard Equipment have supplied the U.K. AEA with a 4.3 MeV linear accelerator designed for radiographing pressure vessel welds on power station construction sites. A self-contained mobile unit, the basic design of this equipment was described in *Nuclear Engineering*, November, 1960, pp. 518-519. Its first site application will be for the examination of the 3½-in.-thick welds on the pressure vessels at Trawsfynydd. In its present form the equipment weighs two tons.

Electronic Associates, of Burgess Hill, Sussex, have been awarded a contract for the supply of an analogue computer system as part of a simulator for the *Polaris* missile-launching submarine programme.

Humphreys and Glasgow have signed an agreement with Limex, an East German state trading corporation, for a two-way exchange of technical information related to chemical engineering.

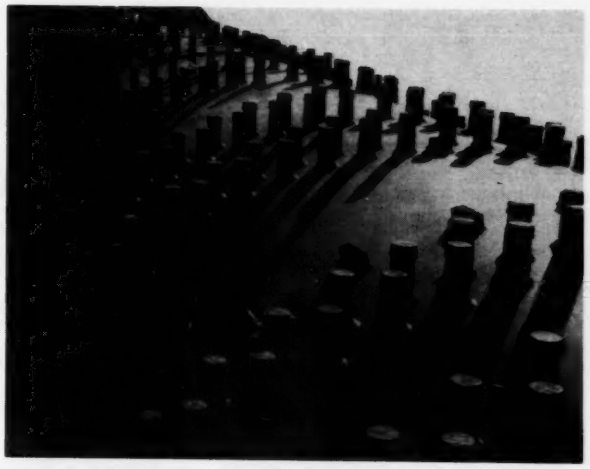


Simulation of the core for Hector is carried out in this temperature stability test rig at Heston works of Fairey Engineering, major contractors to the U.K. AEA for the design and construction of Hector for Winfrith.

Lancashire Dynamo and Crypto are to supply the permanent magnet motors to be used for operating the reactor control rods at Trawsfynydd.

Giffels and Rossetti, of Detroit, Michigan, have been signed up by the U.S. AEC for carrying out design architect-engineering services on the natural circulation reactor test plant to be constructed at the N.R.T.S., Idaho.

Integra, Leeds and Northrup, the instrument and heat-treatment furnace manufacturers, of Birmingham, are now wholly owned by the Leeds and Northrup Company of Philadelphia and have had their name changed to Leeds and Northrup.



The nuclear industry is nothing if not photogenic even if all the photographer requires is a study in light and shadow. This view of one of the Calder Hall boilers is just one of the many examples of the photographer's art as applied to nuclear energy which can be seen at the "Atom in Camera" exhibition at Ilford House, London. Arranged in conjunction with the U.K. AEA the display provides a pictorial background to the growth of nuclear energy in this country. It ends in mid-February.

Baird-Atomic, of Cambridge, Massachusetts, have acquired the Dutch nuclear instrument firm, Electronisch Kernfysisch Apparatenfabriek, N.V., Hartogstraat 5a, The Hague.

M. and C. Nuclear, of Attleboro, Massachusetts, are to fabricate the fuel elements for the Allis-Chalmers "Pathfinder" CRBR project at Sioux Falls, South Dakota. First shipment of the 142 fuel assemblies involved is scheduled for November, 1961, and completion of the entire core loading by February, 1962.

Spencer Chemical Co., of Kansas City, are to supply approximately 40,000 lb of ceramic-grade uranium dioxide to be used for fuel fabrication in the initial loading of the Humboldt Bay BWR plant.

Atomics International have established an energy conversion department with responsibility for the development of projects in thermionic devices and fuel cells.

Marconi Instruments have signed an agreement with the Computer-Measurements Company of Sylmar, California, for the manufacture and sale of the CMC range of counters outside North America and Japan.

"The Professional Engineer—His Employment and Development" is the title of a conference to be held by the **Engineers' Guild** in London on March 22.

Boving and Co. are to supply 32 butterfly valves for controlling the condenser water cooling system at Dungeness.

Vitro Corporation of America have bought up the minority interest in the Vitro Chemical Co. previously owned by the French company, Pechiney. Vitro have also entered into royalty and know-how exchange agreements with Pechiney.

Cape Asbestos have formed a subsidiary, Cape Insulation and Asbestos Products (CIAP), to take over the management of the thermal insulation, packings, jointings and textile side of their business. The work of the present contracts division will also be undertaken by the new company.

Ultra Electronics have designed special magnetic amplifiers for use in the reactor control system at Hinkley Point. A £30,000 contract for the production of these amplifiers has now been placed.

Electric Resistance Furnace Co., a member of the Efco Group of companies, have changed their name to Efco Furnaces.

Head Wrightson India has been formed by Head Wrightson and Co. with headquarters in Calcutta.

Furzehill Laboratories, of Watford, have taken over the production, sales and service of the range of stroboscopes previously manufactured by Watford Instruments under the name of "Strobolyser."

Isotopes Inc., of New Jersey, have cut the price of their radiocarbon dating service by 25%.

Ultra Electronics have purchased a one-third share in Miles Electronics, computer manufacturers. Another third of the share capital is owned by the Lombard Development Corporation.

The Automatic Control Division of Constructors John Brown has been formed into a wholly owned subsidiary company known as **Automatic Control Engineering.** The address is Roxby Place, Seagrave Road, London, S.W.6. Telephone: Fulham 7761.

G. A. Harvey and Co. (London) have moved their sales department to Villiers House, Strand, London, W.C.2. Telephone: Whitehall 9931.

General Dynamics have moved their executive offices to General Dynamics Building, 1 Rockefeller Plaza, New York 20, N.Y. Telephone: Circle 5-5000.

L. E. Simmonds, manufacturers of relays and control equipment, have moved into their new factory at Thetford. With the extra space available it is hoped that the company's output will be doubled.

Wakefield-Dick Industrial Oils, a member of the Castrol Group have changed their name to Castrol Industrial, in line with the change made to the parent company's name last August.

The Firth Cleveland Group have acquired premises at 7 Cleveland Row, St. James's, London, S.W.1, adjacent to the group's headquarters at Stornoway House. The new offices will be occupied by the homes sales divisions of Simmonds Aerocessories, Firth Cleveland Instruments and Surform (Firth Cleveland Tools) and the home and export sales departments of British Lead Mills, Seculate and Richard Hill. Telephone: Whitehall 3100.

J. G. Statter and Co. have moved their sales department from London to their works at Amersham Common, Bucks. Telephone: Little Chalfont 2671.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 837,658. Process for the conversion of energy. H. J. Koek. To: N. Jong.

A gaseous working medium containing particles having a positive charge and free electrons is ionized by means of rays emitted from a radioactive material container removably attached to the generator. The container can be screened by a movable shutter assembly comprising sections with a different permeability for radiation to control the amount of radiation.

B.P. 838,443. Thermonuclear apparatus. A. W. Aikin. To: Metropolitan-Vickers Electrical Co., Ltd.

A very strong magnetic field (100,000 gauss) is produced in an evacuated reaction chamber in axial direction and electrons are introduced into the chamber along the axis of the field. An ionized light gas or mixture of such gases (deuterium or tritium) is introduced radially from a source surrounding the field and the heat generated is transferred to a power plant.

B.P. 838,450. Nuclear reactors. A. M. Cocks. To: John Thompson Nuclear Energy Co., Ltd.

An arrangement of fuel elements in the channels of a graphite moderator with spaces in each channel not loaded, or dummy-loaded, cyclically changing the loaded channels in groups of channels at successively lower levels (in vertical fuel channels) requires less gas flow through each channel for the same fuel heat rating. With the same ratio of gas volume to fuel volume, smaller channels can be used.

B.P. 838,528. Nuclear reactor. To: General Electric Co. (U.S.A.).

A pressure enclosure surrounds the core assembly. A neutron reflecting means is placed outside the enclosure. This reduces the size and simplifies the design of the pressure enclosure and provides a readily accessible high neutron flux region outside the enclosure.

B.P. 838,551. Plasma-containing structures. R. Carruthers. To: U.K. Atomic Energy Authority.

The wall is formed of a multiplicity of mutually insulated metal members, each presenting to the plasma a surface having an area less than the critical area where arc spots are liable to occur which otherwise may result in contamination of the discharge.

B.P. 838,838. Fissile material elements and method of producing fissile material rods for such elements. To: Sulzer Frères Soc. An. (Switzerland).

A rod is formed of a cooling tube embedded in fissile material. The rod preferably consists of a number of fissile (cylindrical) sections separated from one another and arranged in a row along the cooling tube. An element may contain a number of rods held together by a graphite tube, the interstices between the rods, and between rods and tube, being filled with graphite. The element is protected externally by a gastight jacket of a neutron-permeable metal.

B.P. 839,824. Devices for pumping electrically conductive liquids. E. H. W. Schmidt (Germany).

The temperature difference between the liquid and a heat source or a heat sink is utilized to produce thermo-electrically a direct current flowing through the liquid (sodium or potassium) at right angles to the direction of flow and to a steady magnetic field extending through the liquid.

B.P. 839,940. Nuclear reactor control. To: Commissariat à l'Energie Atomique (France).

The control system refers especially to reactors used as propulsion plants for ships, submarines, etc. Cyclic variations, preferably low-amplitude sinusoidal variations, are imposed on the multiplication factor of the reactor which results in cyclic variations in an operating parameter (neutron density), exclusively as a function of reactivity. These variations are translated into electric signals corresponding to the variations in the multiplication factor and in the parameter (neutron density) and the signals, through a phase comparator, then operate the control rods for controlling the rate of reaction.

B.P. 840,010. Nuclear reactors. N. Battle. To: Rolls-Royce, Ltd.

A fuel element is built up of a number of thin rectangular sheets formed from clad fissile material (in aluminium, steel, zirconium, niobium, beryllium). The sheets are provided with corrugations inclined at 45° to their lengthwise axes and are stacked with the corrugations of adjacent sheets in contact with, and running across, each other, in open-ended (rectangular) tubular containers through which the coolant passes.

B.P. 840,017. High energy gaseous discharge devices. To: U.S. Atomic Energy Commission (U.S.A.).

Vitreous materials (quartz, ceramic, porcelain, glass) as used hitherto for such (laboratory) apparatus have certain disadvantages. Contamination of the ionized gas occurs by evaporation during discharge, and the vessels are liable to breakage under the resulting shock. A discharge tube is therefore made up of a metallic envelope enclosing a pair of electrodes and a metallic shell around the discharge path between the electrodes. This shell is composed of spaced helical turns of a first metal ribbon connected to one electrode and of spaced helical turns of a second metal ribbon connected to the other electrode bridging the gaps between the turns of the first metal ribbon and with insulating material inserted between the superposed parts of the two helices.

B.P. 840,203. Coating of tantalum. To: U.S. Atomic Energy Commission (U.S.A.).

Tantalum can be protected against attack by molten uranium by heating the tantalum in contact with elemental boron *in vacuo* at 1,800°C for five minutes. A boride layer is thus formed. After removal of the boride-coated tantalum from its contact with the boron, it is converted to tantalum monoboride by further heating in a vacuum at (at least) 1,800°C for five hours.

B.P. 840,332. Nuclear reactors. D. R. Smith, R. S. McKean. To: A.E.I.-John Thompson Nuclear Energy Co., Ltd.

The coolant flow in gas-cooled reactors with vertical fuel channels must be varied as the neutron flux density varies and the coolant temperature in the outer channels will be below that in the central channels if the flow in the outer channels is not throttled by a gag. The gag must not be a heavy mass of metal which would absorb too many neutrons. On the other hand it must withstand the displacing force of the coolant flow without a mechanical latching device. The solution is a flow restrictor of such a shape that the pressure of the coolant flow is small. The inner removable member of the gag is cylindrical for the major portion of its length and has a decreasing cross-sectional area at its lower end.

B.P. 840,333. Nuclear reactors. D. R. Smith, D. F. Bins. To: A.E.I.-John Thompson Nuclear Energy, Ltd.

The cross-sectional area of the path of the coolant (gas) is increased at the bottom of one or more of the vertical fuel channels by reducing the diameter of the cooling fins of the fuel elements at the ends of those channels, or by increasing the diameter of the channel, where the coolant enters, over a distance equal to the length of one or more fuel elements.

B.P. 840,577. Heat exchangers. To: Stein et Roubaix (France). (Add. to: 819,825.)

Refers to heat exchangers through which a radioactive fluid flows, e.g., as in nuclear reactors. The bends are made with an inner floating head so that the internal tubes can freely expand within the outer envelope.

B.P. 840,609. Plated cans for fuel elements. To: Deutsche Gold- und Silber-Scheideanstalt vorm. Roessler (Germany).

A zirconium tube coated externally with steel (thickness of layer 50 to 200μ).

B.P. 840,740. Steam stirred homogeneous nuclear reactor. To: U.S. Atomic Energy Commission (U.S.A.).

The design is particularly suitable for a research device where a maintenance-free reactor of moderately high neutron flux is desired. The characteristic feature is the arrangement of vertical small diameter tubes in the region of criticality to provide circulation of the liquid fuel with a geyser effect for forcing fuel out the top of these tubes when the fuel is heated, the volume of liquid fuel having a level equal to or slightly below the upper extremity of the tubes. The liquid fuel is returned through a channel from the top of the tubes to the region of criticality. Heat exchanger means are located in the channel.

B.P. 840,753. Plates with oxide inserts. To: U.S. Atomic Energy Commission (U.S.A.).

Oxide fuel pellets are positioned in rows of passages in plates easily attached to each other in spaced relationship so as to provide ample spaces for the coolant fluid flow. The pellets are thermally bonded to the passages by a lead filler so that there is no need to finish passages or pellets to exact size.

Processes and Equipment

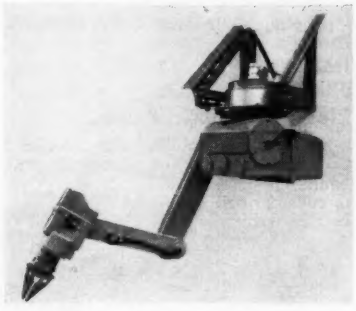
For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

New Remote Handling Designs

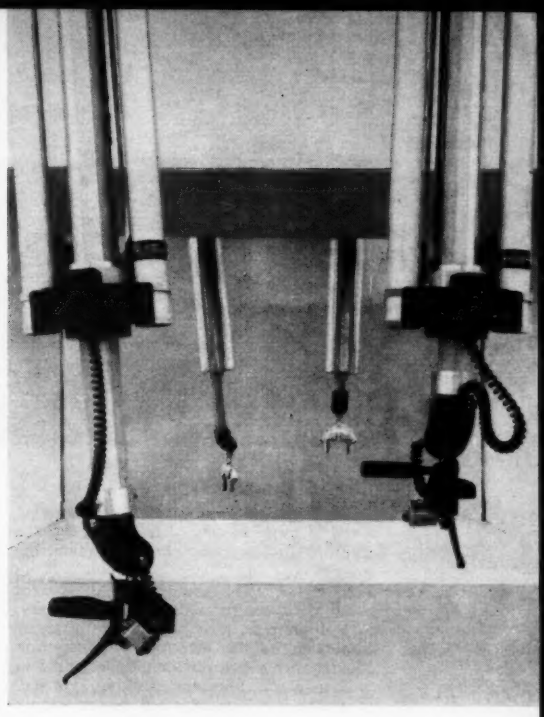
The Savage and Parsons master-slave manipulator is well known in the industry, having been described in *Nuclear Engineering* as long ago as April, 1957 (p.160). While the SP8 (now known as the NE8) is still standard for comparatively light loads (such as the radiochemical work for which it was designed) a new model, the NE9, has been developed to suit loads in the order of 30 lb (all manipulations) 96 lb direct lift (grip) and 120 lb direct lift (hook).

The new design, while retaining the basic overall dimensions of the previous unit, is of heavier construction, and the operating wires for some of the movements have been replaced by roller chains. Modifications have also been made to the handles, which are of the pistol-grip type, and the jaw mechanism has been redesigned. Where electrical actuators are fitted to give three positions of the slave arm relative to the master arm, the control switch is now mounted on the pistol grip. Some 60 sets of this model have been ordered by the U.K.AEA, while a number are on order for abroad.

Following the formation of Nuclear Equipment, Ltd. (*Nuclear Engineering*, July, 1959, p.319) equipment of General Mills (U.S.) design is now available, in the form of several types of mechanical arm. Illustrated is the GM150, which is a compact unit for alpha-gamma handling in air-tight dry boxes; it can be mounted on wall, ceiling, or on a boom or bridge. Apart from any mobile mounting, the unit has six motions; continuous rotation of the entire arm; pivoting of shoulder and elbow; pivoting and rotation of wrist; a grip opening of 2¼ in. A load of 40 lb can be lifted, with a jaw grip of 75 lb.



The GM150 mechanical arm remote handling unit.



The NE9 master-slave unit.

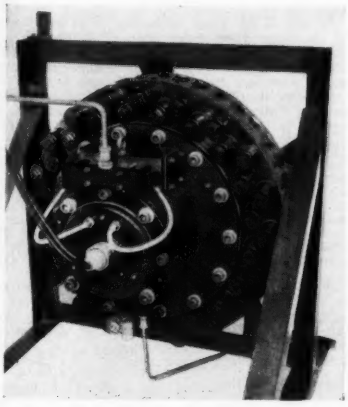
Other models range from the GM100 which is a low-cost unit with full cell coverage (i.e. travel and traverse motions on rails) designed for handling 40 lb in all directions or 200 lb direct lift with hook, to the GM700, which has a manipulating capacity of 500 lb and a direct lift of 5,000 lb.

(*Nuclear Equipment, Ltd., Crossroads House, Watford, Herts.*)

1048

Trawsfynydd Sampling Valve

The 40-way automatic sampling valve developed by Plessey for the Trawsfynydd burst slug detection system has a number of interesting features. Since continuous operation is required over a period of years, it is scarcely necessary to say that both detail design and materials have received close attention; should maintenance or inspection be required, it is possible to remove the moving parts as a unit, the "sniffer" pipes being automatically sealed. A further good point is the use of pneumatic operation for stepping the valve, thus doing away with operating shaft glands and a possible source of leakage.



The 40-way sampling valve developed by Plessey for Trawsfynydd.

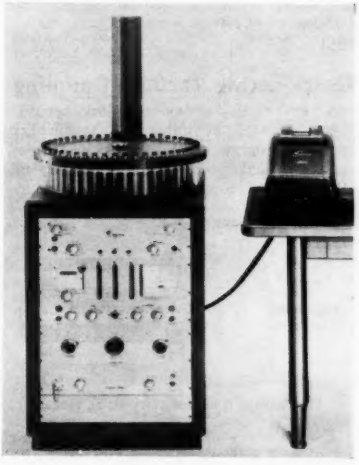
A further development for Trawsfynydd is an equipment based on the characteristic alpha display of uranium for the detection of serious element failures during shut-down.

(*Plessey Nucleonics, Ltd., Weedon Road, Northampton.*)

1049

Automatic Sample Changer

Measurement of large numbers of gamma-emitting samples is facilitated by a recently-developed Nuclear-Chicago automatic sample changer, which has a capacity of 49 capped test tubes. These are loaded into a rotating indexing table, and each sample, in turn, is lowered by an elevator into a heavily-shielded well-type scintillation counter, the elevator mechanism being designed to ensure that each tube is "bottomed" in the crystal, irrespective of slight variations in dimensions, thus giving reproducibility of results. At the end of each count, the unit automatically prints the results, identifies the sample, and changes it for the next one. The number of counts preset, with a 4—1,000 decade scaler can be varied from 4—100,000. To prevent a weak sample delaying a run, the unit can reject a sample after either 15 or 60 min. The system can be left completely unattended at nights or week-ends.



The Nuclear-Chicago automatic sample changer.

(*Continental Distributors, Ltd., 121 Earls Court Road, London, S.W.5.*)

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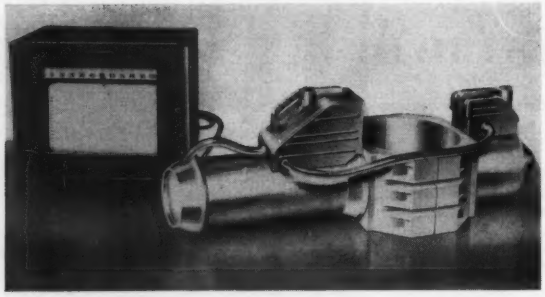


Left: The Saunders-Roe and Nuclear Enterprises' type 336 liquid density gauge.

Right: The new Stonebridge Electrical hand monitor equipment.

Liquid Density Gauge

The type 336 density gauge for observing liquid density without interruption of the pipe run, utilizes gamma-ray absorption, the source in the standard unit being caesium-137. The source strength is kept low (e.g., 25 mc for a liquid of unit density, in a 10-in pipe with walls 1 in thick) by employing as the detector, a scintillation counter with a 5-in photomultiplier and 5 in × 2 in plastic phosphor working as a d.c. generator. A transistorized power supply provides power to the dynodes to give an overall gain of 10^5. A current of the order of 10μA is fed to a Honeywell-Brown recorder with an input impedance of 1MΩ. Automatic standardization is carried out every 10 min to counteract any tendency to drift, by replacing, by means of shutters, the measuring beam with a beam from a standardizing source. The range covered by the recorder is adjustable and the zero set by a helical potentiometer.

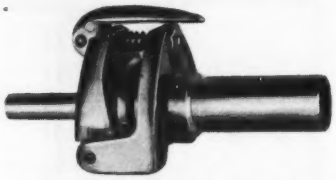
The detector head and its associated clamping gear are of massive construction which smooths out temperature changes. An accuracy of $\pm$0.1% is given with a response time of 10 sec, but this can be improved to $\pm$0.01% with longer response times. Smaller models are available for smaller pipes; there is also a pressurized type for use in explosive atmospheres.

(Saunders-Roe and Nuclear Enterprises Ltd., 45 Parliament Street, Westminster, London, S.W.1.)

1051

Quick-acting Vacuum Coupling

A new quick-acting coupling, enabling rapid breaking of joints in vacuum lines, for maintenance or rebuilding test rigs is stated to have leak-tightness better than 10^{-9} cm^3/sec. Each half of the joint has a



The Appleby & Ireland quick-acting vacuum coupling.

flange with a raised lip; a collar fitting over these lips centres the two flanges, and controls compression of a surrounding O-ring, which provides the actual sealing. The two halves are held together by a light alloy clip, with a lever-operated cam; adjustment is provided by a hexagon nut, locking into position every 60°. Apart from the clip, the coupling is in stainless steel, and the parts can be argon-arc welded to existing pipe lines, or supplied with stubs and couplings for flexible piping, or with tees, crosses, or reducers. Rapid-closing cocks and electromagnetic valves can also be supplied.

(Appleby & Ireland Ltd., Basingstoke, Hants.)

1052

Electromagnetic Valves

Electromagnetic valves, manufactured by Concordia G.m.b.H., of Stuttgart, are now available in Britain through the sole distributors, Londex, Ltd.

A typical electromagnetic valve in the Londex range.

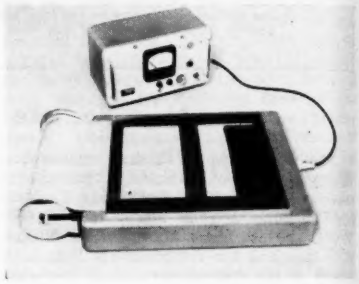
The range is wide, covering valves of all types, for air, gas, or liquids, with bodies of brass, stainless steel, or plastics, and includes models suitable for continuous high-speed operation (up to 48,000 operations/hour) and types able to close against pressures up to 1,400 p.s.i.

(Londex, Ltd., Anerley Works, 207 Anerley Road, London, S.E.20.)

1053

Hand Monitor

A new monitor unit for measuring contamination on hands (or feet, if a strong grating is used to take the weight off the



instrument) has a detector with two separate windows, with three tubes to each window. The tubes are protected by gratings and two foils, one for light exclusion and one for mechanical protection. To prevent contamination of the upper foil, a layer of paper is used, which is torn off as required. All six tubes are normally connected in parallel, but a selector switch provides individual checking. The unit has visible and audible indication, two trip circuits, and is fully transistorized.

(The Stonebridge Electrical Co., Ltd., 6 Queen Anne's Gate, London, S.W.1.)

1054

BRIEFLY . . .

Fire alarm operating units, complying with the Ministry of Labour's recent order, are offered by **Dewhurst and Partner, Ltd.,** Inverness Works, Hounslow, Middlesex. Make- or break-circuit types are available, either with glass-covered push-button or operating by breaking the glass alone. **B211**

Rockweld, Ltd., Commerce Way, Croydon, Surrey, have introduced the Comet Series II automatic CO_2-shielded welding unit. Improvements include the mounting of the CO_2 cylinder on the welding trolley, and a new method of electrode feed, enabling one coil to be fed in after another and eliminating wastage. The unit can now be operated from any type of power source of sufficient capacity. **B212**

Semi-Elements Inc., Saxonburg Boulevard, Saxonburg, Pennsylvania, announce that they have developed magnesium oxide doped with rare earths, such as praseodynium, samarium and neodymium oxides. Single crystals can be obtained approximately 1-3 mm x 4 mm long; polycrystalline specimens may be obtained much larger. Doping with europium, gadolinium and terbium will, it is hoped, soon be achieved. MgO has also been produced in fibre form, only a few microns thick, on a laboratory basis; it is not yet available commercially. **B213**

A new lightweight pneumatic hand tool, the CP 3017 F, is being marketed by the **Consolidated Pneumatic Tool Co., Ltd.,** 232 Dawes Road, London, S.W.6. Suitable for taking either a saw blade or file, it gives a ¾-in stroke at 1500 strokes/min and weighs only 5 lb. **B214**

The electronics division of **Westinghouse Electric International Company,** 40 Wall Street, New York 5, announce that they have developed a new photoemissive material which maintains a high level of sensitivity at temperatures up to 250°F. It also has a "dark current" less than 1% of that of conventional materials. **B215**

A new stabilized-voltage power pack is announced by **W. G. Pye and Co., Ltd.,** Granta Works, Cambridge. The output range includes d.c. outputs from 0 to 500V, and fixed and variable negative supplies of −250V, all containing less than 0.003V ripple. Two separate a.c. supplies of 5A at 6.3V are provided. Paper capacitors are used throughout. **B216**

Interlas Ltd., 9 Church Street, Ampthill, Bedford, are marketing a new range of welding positioners. These range from the DB15 bench model for a 33-lb load, with an infinitely variable speed from 0.3-3.0 r.p.m., to models for 2 and 5 cwt, and 1, 1½, 2½, 3½, 6 and 10 tons. **B217**

A new X-ray image intensifier, with an increase in intensity 3,000 times that of a conventional fluorescent screen, is announced by **Tracerlab,** 1601 Trapelo Road, Waltham 54, Massachusetts. Automatic brightness control is fitted, and facilities for closed-circuit TV, and/or 16mm, 35mm cinematograph, 35mm still, or Polaroid cameras can be provided. **B218**

Type SCM "Tan-Ti-cap" solid tantalum electrolytic capacitors are announced by **Texas Instruments Ltd.,** Dallas Road, Bedford. Ranging from 1 to 330μF with either 10% or 20% tolerance they are made for working voltages of 6, 10, 15, 20, 25 and 35V d.c., and are suitable for operation at full working voltage from −55°C—85°C, and 2/3 working voltage at 125°C. Failure rate is said to be better than 10^5 at max. rating. **B219**

Production of a four-way fused and shuttered socket outlet for 4-13A flat-pin plugs is announced by **British Central Electrical Co., Ltd.,** Briticent House, 6/8 Rosebery Avenue, London, E.C.1. Of unbreakable construction, it may be obtained in rubber or neoprene. **B220**

Circular magnetic chucks (permanent magnet) from 6-24 in diameter have been added to the Darwins-Fimax range manufactured by **Darwins Ltd.,** Tinsley, Sheffield 9. The chucks, which are intended for lathe or similar work, have a speed limit of 3,000 r.p.m. for the smallest size to 750 r.p.m. for the largest. **B221**

The upper temperature limit of Metalife duplex metal coating, recently described in **B198** (*Nuclear Engineering*, December, 1960) should be 400°F, and not −400°F, as stated.

Disposable Overalls

Of potential interest to the nuclear industry is a range of disposable paper overalls where it might be more economical to burn them

Miller Rayner paper overalls.

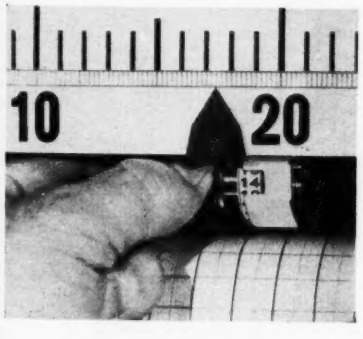
rather than to make arrangements for extensive laundering. They are said to have high tensile strength, to be water- and flame-resistant, and to have the same electrostatic properties and resistance to acids and alkalis as cotton fabrics.

(Miller Rayner (Overalls) Ltd., Lorenzo Drive, West Derby, Liverpool, 11.)

1055

Multi-point Recorder

The number of points recorded on a strip chart may be rapidly changed on a new Honeywell design, the Universal ElectroniK.



Replacing the print-wheel unit on the new Honeywell recorder.

By replacing the print-wheel indicator dial unit, fixed by a thumb nut, and replacing a shorting plug on an input terminal board inside the instrument, the recorder may be made suitable for 2, 3, 4, 6, 8, 10, 12, 16, 20 or 24 points. This arrangement can be supplied on any of the range of non-control recorders, and is extremely convenient for research work or process applications where the number of points to be monitored may change frequently.

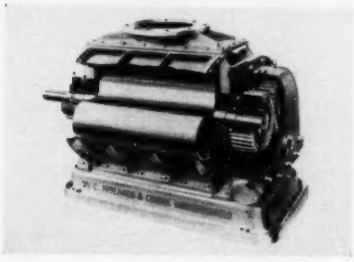
Further flexibility in application is provided by the ability, with this design, to change the range by slipping in different resistor cards, or to compensate for different types of measuring unit by slipping in a new input terminal board.

(Honeywell Controls Ltd., Greenford, Middlesex.)

1056

Modified Blower Design

Fabricated impellers, larger shafts and bearings permitting increase in working pressures of 10–15 p.s.i., and new sealing



Sectioned view of a Holmes-Connersville RBS blower.

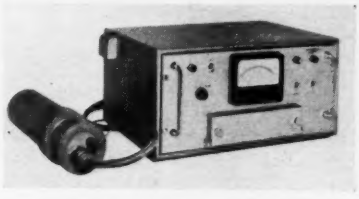
arrangements to prevent the possibility of contamination of the air by oil, are amongst recent modifications to the range of type RBS Holmes-Connersville positive blowers. For use with gases other than air, a range of mechanical seals gives considerable improvement over the stuffing boxes previously used.

(W. C. Holmes and Co., Ltd., P.O. Box B7, Turnbridge, Huddersfield.)

1057

New Continental Instruments

New Intertechnique instrument developments include a d.c. logarithmic amplifier covering 6 decades with a drift of less than 0.1 decades from −40°C–+70°C. In con-



The Intertechnique logarithmic d.c. amplifier, with pressurized ionization chamber.

junction with a pressurized ionization chamber, it is suitable for monitoring radiation doses from 1 mr/h–1,000 r/h. It can be supplied in battery-operated form for use in car, plane, or helicopter.

Other recent developments include a fast scaler with a resolving time of 10 n sec and a recurrent frequency of 20 Mc/sec, capable of triggering a conventional scaler; and a triple-pulse generator for test purposes, particularly with transistorized equipment.

(Intertechnique S.A., Division Nucléaire, 94 Avenue de Paris, Versailles (S. & O.).)

1058

CATALOGUES

Kelvin and Hughes, Ltd., New North Road, Barkingside, Essex, have issued a number of additions to their Components Catalogue, including provisional data on governed induction motors, teletorque synchronous transmission units and pressure-responsive devices.

Industrial and portable air compressors are described in leaflets CB.193 and 195 received from **B.E.N. Patents, Ltd.,** High Wycombe, Bucks.

A leaflet from **Thos. W. Ward, Ltd.,** Albion Works, Sheffield, describes the improvements in the design of their Twin Bucket Weighbatcher for concrete mixing.

Dawe Instruments, Ltd., Harlequin Avenue, Great West Road, Brentford, Middx., have issued an abridged catalogue of instruments.

Plastic finishes for all services are described in a booklet received from **Plasinter Co., Ltd.** (The Plastic Finishing Co.), Progress Works, Holyhead Road, Wednesbury, Staffs.

Descriptive matter on horizontal drum truck mixers and agitators and high discharge truck mixers with hydraulic drive, and an amusing little publication "The Truck Mixer Man" (which should be in the hands of every driver), are amongst the publications recently issued by **Ransomes and Rapier, Ltd.,** P.O. Box No. 1, Waterside Works, Ipswich.

Leaflets received from **Nash and Thompson, Ltd.,** Oakcroft Road, Chessington, Surrey, cover flow control switches and metallurgical equipment, including creep rupture machines and furnaces, and a specimen preparation plant.

Overload and underload relays, automatic weight control and electronic counting and batching equipment, photoelectric control equipment and registration control are described in leaflets received from **Elcontrol, Ltd.,** Electronic Control Engineers, Wilbury Way, Hitchin, Herts.

Dry-box gloves in butyl, said to have one-fifth to one-tenth the permeability of neoprene compounds, are described in a leaflet issued by **Erskine-Healy, Inc.,** Rubber Products Division, Rochester, N.Y., U.S.A.

The Universal Vibrograph for recording vibrations and deflections, draught and pressure indicators, recorders and controllers, the Numalec process controller, and CO_2 recovery and control equipment and recorders are described in leaflets received from **Cambridge Instrument Co., Ltd.,** 13 Grosvenor Place, London, S.W.1.

"This is TI Today" is the title of a booklet received from **Tube Investments Ltd.,** The Adelphi, London, W.C.2, listing their main companies and their products.

Peabody high-efficiency gas scrubbers are described in Bulletin LH203-D received from **Peabody Ltd.,** Peabody House, 300 Vauxhall Bridge Road, London, S.W.1.

Wrought zirconium, the corrosion resistance of titanium and the properties of copper alloy rods and sections are recent Metals Division publications from **Imperial Chemical Industries Ltd.,** P.O. Box 216, Birmingham, 6.

Ferranti Ltd., London Computer Centre, 68/71 Newman Street, London, W.1, have issued a new classified index of Ferranti computer literature.

"The Harvey Team" illustrates the activities, products and personnel of **G. A. Harvey and Co. (London), Ltd.,** Greenwich Metal Works, London, S.E.7.

Turner Brothers Asbestos Co., Ltd., P.O. Box 40, Rochdale, have issued a new publication (D4) covering the complete range of glass-fibre woven tapes.

An abridged catalogue of electronic equipment has been issued by **E.M.I. Electronics Ltd.,** Instrument Division, Hayes, Middx.

Orbits

EXCEPT when indulging in blear-eyed maunderings about how much better things used to be in his youth, a columnist should not use his column to talk about himself. Nevertheless, in this particular case, it is felt that a brief explanation might be made for a sudden reappearance after an absence of nearly two years. The cause of our abrupt disappearance was what is known to the medical profession as hemiplegia (more commonly known as a stroke) and we have been learning a new time scale. In the field of nuclear instrumentation, "paralysis time" is measured in microseconds; with this lark, it is comparable with the gestation of elephants, the maturing of liqueur whisky, or the obtaining of information from some of the consortia. However, with the aid of a spring-loaded tin leg (actually of aluminium alloy) and a stick, we are much more mobile than the average glacier and, in fact, slip around with the lithe grace of a hippopotamus with a slipped disc. Since the alloy of the tin leg cannot be guaranteed boron-free, we are barred from reactors under clean conditions. Otherwise, we are once more within your midst. You have been warned.

Black Box-ery

A recent visit to Edinburgh, to see the first unit of the low-frequency generators for the Trawsfynydd control rod supply (elsewhere, this issue) was very nearly the cause of a flood of those blear-eyed maunderings (see first par.). Generation is almost entirely static; some of the units have a motor-driven magslip—and the elimination of even this is the ultimate goal. Yet from our student days, the name of Bruce Peebles has meant the Peebles-La Cour Motor Converter—worthy of capital letters since it was one of the most ingenious machines ever devised. Briefly, it looked like a straight motor-generator, but had connections between the 12-phase rotor winding of the motor, carried through a hollow shaft to tappings on the d.c. armature windings. The a.c. end started like an induction motor (no boss shots in synchronizing) and ran half as a motor and half as a transformer, while the d.c. end ran half as a d.c. generator and half as a rotary converter (if you could really understand the vector diagrams, you were pretty certain of a First). It combined a higher efficiency than a motor-generator, with the absence of temperamental outbursts, to which the rotary was sometimes subject.

The motor converter must have died with the rotary, killed by the mercury arc which itself is seeing, in the silicon rectifier, the writing on the wall. Yet somehow, in our childish innocence, we had never ceased to think of it in connection with B.P. And to be shown, as their latest development, something from which mechanical movement had almost been eliminated, felt rather like being invited to tea by, say, Sir Malcolm Sargent, and spending the afternoon listening to "pop" records. Just not what one had expected.

"King-Size"

What one did expect, once the fact of black boxery had been accepted, was that the boxes would, if not necessarily black, be robust. They were. Standing about 6 ft high, and weighing about a ton each, they were "king-size" in every respect. Lest manufacturers of light equipment think that we are belittling their products, let us hasten to assure them that we are not. You do not take a Scammell round the West End for afternoon shopping—you don't take a bubble car for 10 tons of coal. Fitness for purpose. In the same way, you don't use printed circuits for 30-40 amps. You use connections that you can get a spanner on, and magnetic amplifiers that look like (and, in fact, are) pups off power transformers. Maybe this is one of the first signs of a new subdivision of industry. "Heavy electronics" . . . how does it sound?

Not all the B.P. effort is being devoted to heavy stuff, however. Their electronics division is comparatively young, but in our all-too-brief tour we saw some remarkably bright ideas under development in matters as diverse as the measurement of the earth's field, and the sorting of tea. We shall be hearing more of them, we fancy.

£iquid Metal$

Glancing at the report of the Dounreay reactor symposium (briefly summarized elsewhere in this issue) one of the most striking features is the large sum expended in using the 70/30 sodium-potassium alloy instead of plain sodium. On the figures given in the papers, a few rough calculations will show that it cost over £50,000 *extra* just to lower the melting point from 98°C to 40°C. Since sodium has better heat transfer and corrosion properties than NaK, and large amounts of trace heating had to be provided anyway, something like £1,000 per degree Centigrade appears a high price for something like the difference between warm and boiling water.

If the extra lolly would have provided the 22/78 eutectic, which is molten at well below atmospheric temperatures, the convenience in operation might have been worth it. But this would have cost £150,000 extra. Maybe it's as well that all concerned decided that lithium—in spite of its attractive heat-transfer properties—was only lying a poor third. That would have run into the half-megaquid range.

Footnote to Above

Mind you, it's frightfully easy to be terribly clever years after a decision has been taken—particularly if you didn't have to take the decision in the first place, and can just sit back in the gallery and boo. Examining the Dounreay scheme as a whole—and taking into account all the off-the-record comments one hears—the team did an amazingly good job, particularly when one considers that they started from scratch. If this is the worst brick that will be thrown, the team should be able to puff out their chests with pardonable pride. After all, when one is working with about forty-eleven unknowns, there is a tendency to play for safety with the snags that one can see. The decision had to be taken at some time and, having been taken, it had to stand. For (as the microbe said, when it found itself dying in the equine digestive tract) you can't swop streams in mid-horse.

Tail-Piece

Since our last incarnation industry—and not only the nuclear field—has undergone so many take-overs, amalgamations and reorganizations that one scarcely knows who is tied up with what. Discounting the comments of City Editors, who always see it from the shareholders' point of view, our opinion of most of these mergers can be summed up in the immortal words of *1066 And All That* . . . "This was a Good Thing, except for the Common People." As we can be (and frequently are) most frightfully common, let's have a go, shall we?

INDUSTRIAL REVOLUTION

The Take-Over's going like clockwork
We're reorganizing the Group,
Disturbing the slumbers of all the back numbers
And making them jump through the hoop;
We're really mad keen to get weaving
(When we've disentangled the threads)
In all revolutions, the normal solution's
To lop off a few of the Heads.

Then . . . interchange all their departments
The length of the land, coast-to-coast,
A sort of exotic, despotic, chaotic,
Industrial General Post;
For pruning the plant of the dead-wood
There's nothing succeeds like the trick,
Of swiftly uprooting old buffers from Tooting
To work up at Wigan—or Wick.

While those who resent this upheaval
Will soon learn that—while without doubt
"Regretting sincerely"—our policy, clearly
Is . . . Co-operation—or Out!
To sling a few bods on the scrap-heap
Before the régime has begun.
Is quite incidental—don't get sentimental
We're not in this racket for fun.

EFFICIENCY will be our watch-word
Well . . . that's what it says in the script,
But, since the whole story is Parkinson's Law-y
We might find that something has slipped;
Might find our reorganization
Has scarcely improved things at all,
And—though it *looks* neater—we've merely robbed Peter
And not really recompensed Paul.

The Take-Over's going like clock-work
(Your Board was determined it should)
And, though there are grumbles and internal rumbles
On paper, it looks pretty good;
While, as for the general public
And all who are not in the know,
Verbose eructations from Public Relations
Will *prove* it's a Jolly Good Show!

Tangent